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NOVEMBER•DECEMBER 2000

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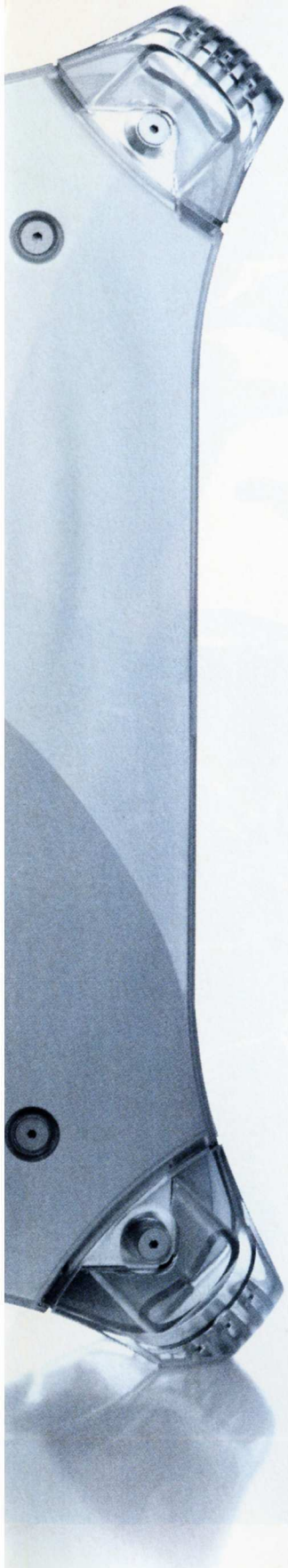
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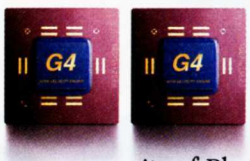
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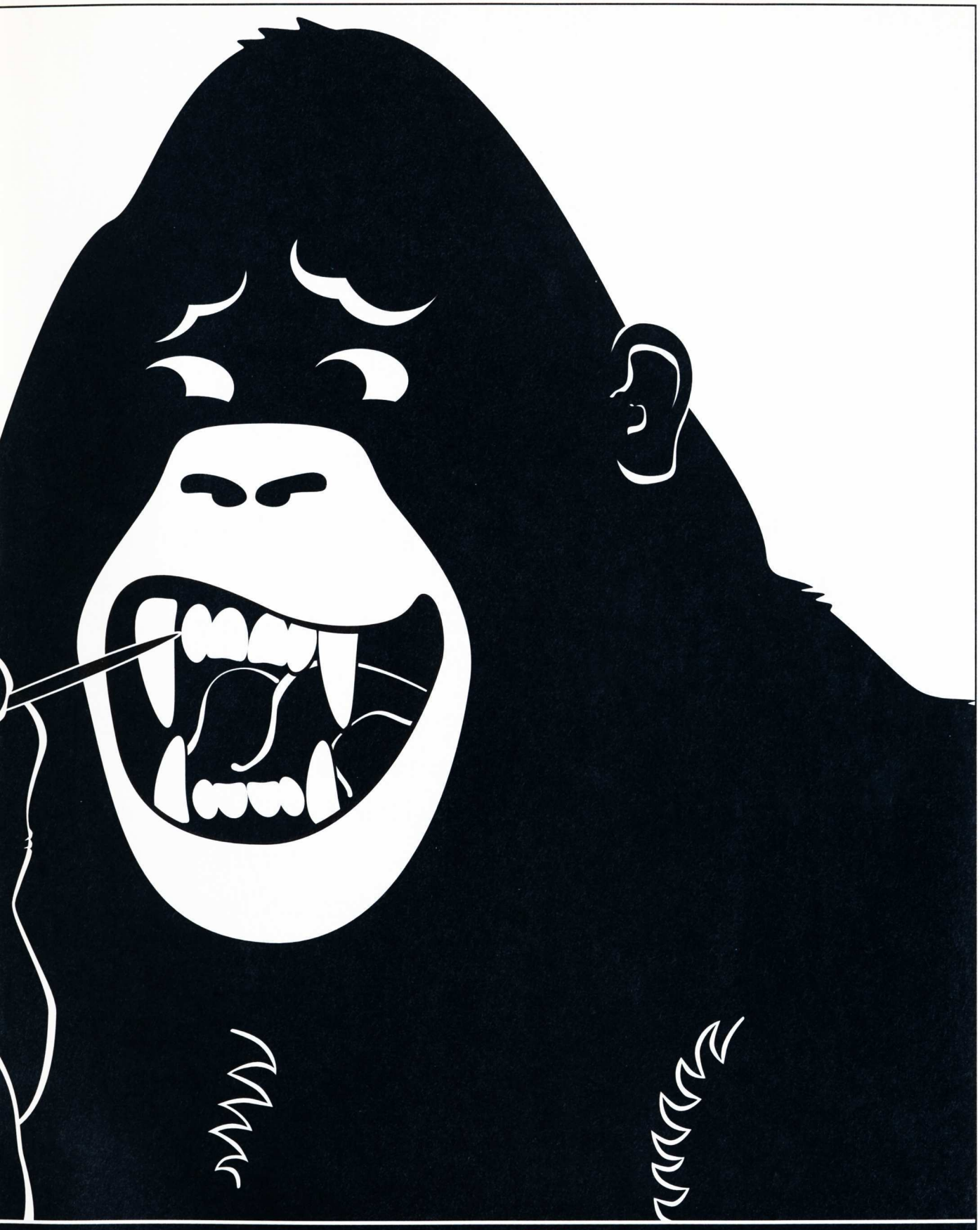
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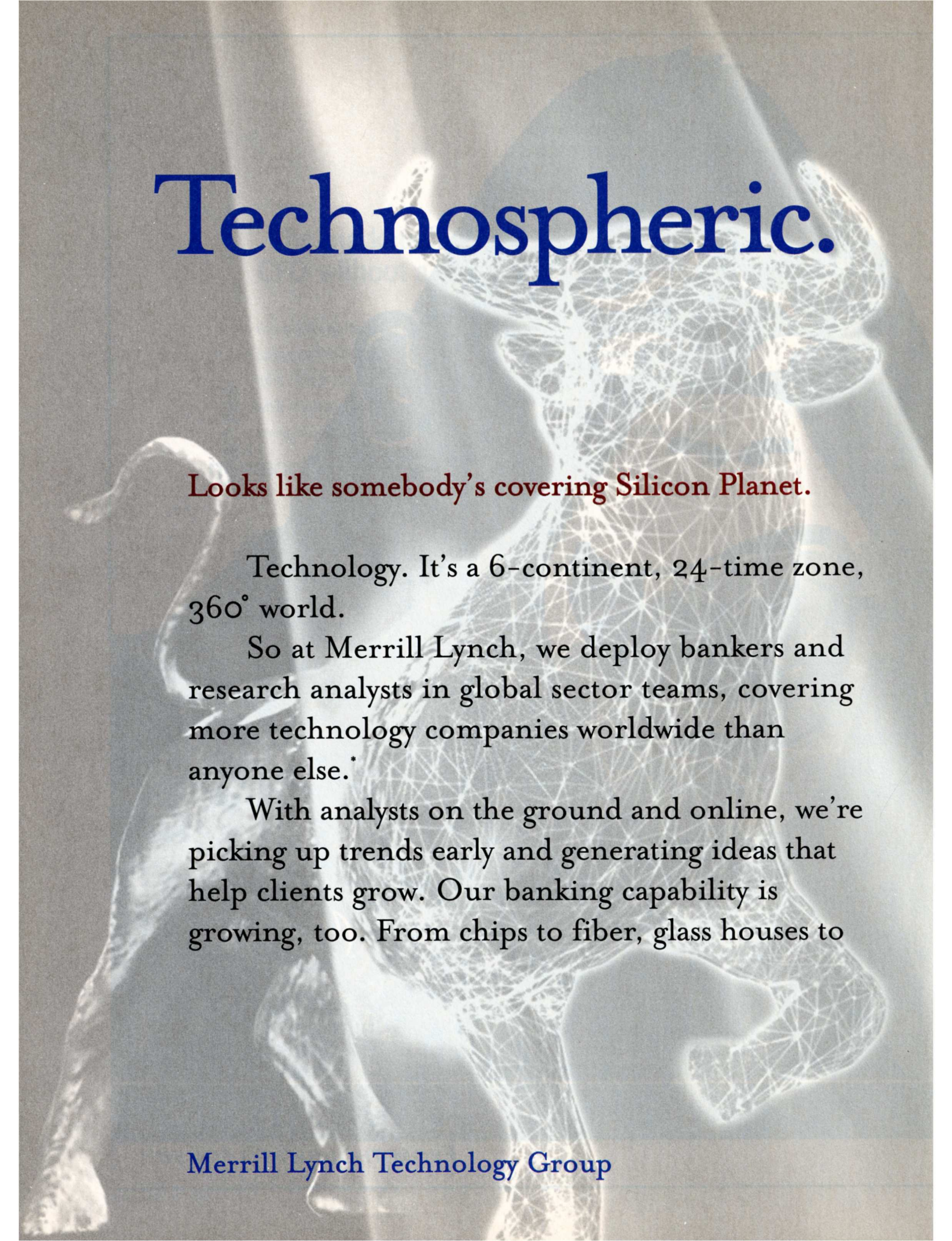
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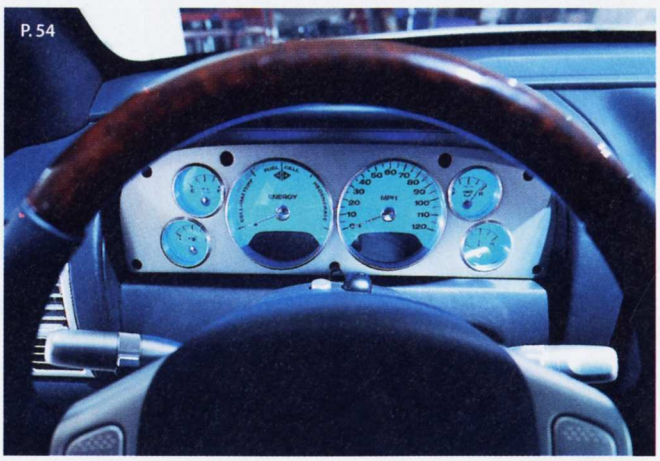
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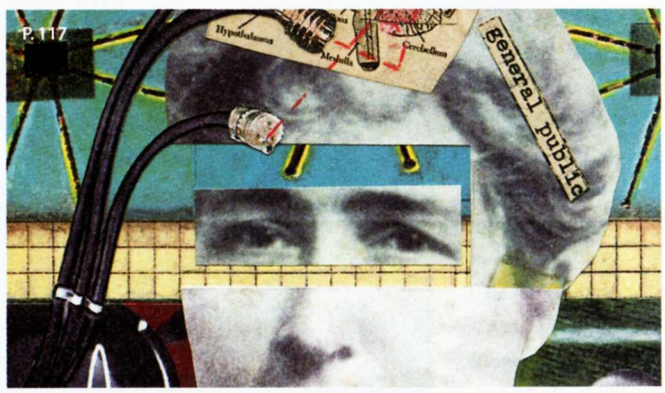
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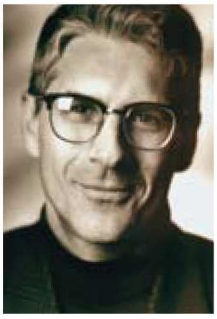
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Punctuated Evolution

TWO AND A HALF YEARS AGO, THIS MAGAZINE UNDERWENT A REVOLUTIONARY transformation, emerging with a new design, a new staff and a new editorial focus on the process of innovation—a fact we proudly announced on our cover, which described us as "MIT's Magazine of Innovation," a tag we still bear. That was the revolution.

But change doesn't end after the barricades have been stormed and a new regime has been installed in place of the old one. In fact, the change of regime was just the beginning of the process needed to make the new *Technology Review* a great magazine. How does a magazine continue to improve after it relaunches itself? Largely by listening to its readers. We've been listening hard over the last two and a half years, both formally, in statistically valid sample surveys of our audience, and informally, via letters, e-mail, phone calls and face-to-face conversations.

We've learned a lot from this concentrated listening. We've learned that, of the different kinds of stories we offer, those that focus directly on the technology rather than the people, organizations and strategies involved in innovation resonate most strongly with our readers. We've learned that information technology, though not an exclusive passion, is very much at the top of people's minds. And we've learned that the technology horizon is relatively circumscribed: Most readers are interested in technologies that will reach the marketplace in the foreseeable future—the next three years or so.



Now we are combining those three lessons into a plan for what we will offer you over the next year: a magazine focusing directly on emerging technology, with an emphasis (though far from an exclusive emphasis) on information technology and a relatively near-term time frame. That's the evolution.

This evolutionary process will be especially visible in our next issue, January/February 2001, a special issue on the "State of Innovation." That issue will incorporate a set of significant changes in the design, content and staff of the magazine, as well as in its frequency. I'll spell out things in more detail in my next column.

These changes are exciting for us here on Vassar Street, and they mark a milestone for the new *Technology Review.* But all major milestones are bittersweet, and the bitter part of this one is that, as we evolve, we will be parting company with some people who have played a key role in the success we've enjoyed so far.

Specifically, this issue marks the last regular appearance in our pages of four writers: Michael Dertouzos, Stephen S. Hall, Wade Roush and G. Pascal Zachary. Each has written a regular column that added enormously to the richness and flavor of the new *Technology Review*. Each of those writers, however, has other important challenges to go on to, and we will present four new columnists in the next issue.

As we part, I'd like to offer heartfelt thanks to these four writers, who took a chance on a new and untried concept—a magazine from MIT about the process of innovation—and devoted their considerable talents to making it a success. Michael, Steve, Wade, Gregg, thanks to each of you for your inspiration and professionalism.

And now, on to the evolution.

—John Benditt

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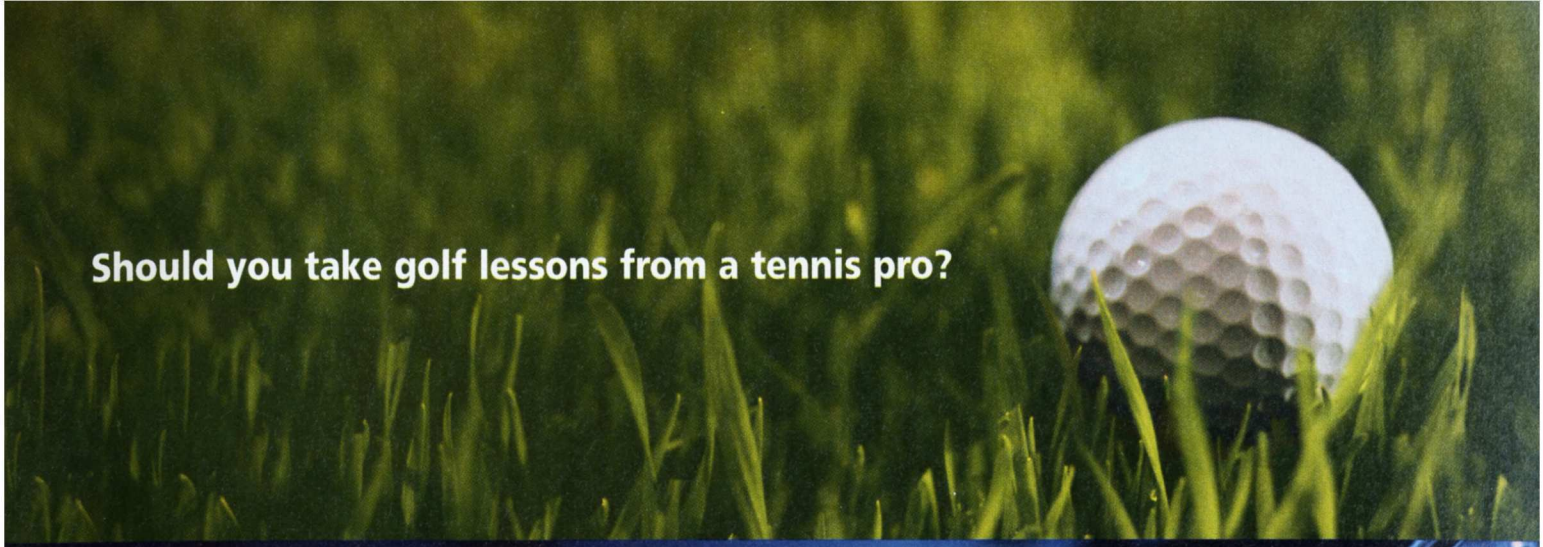
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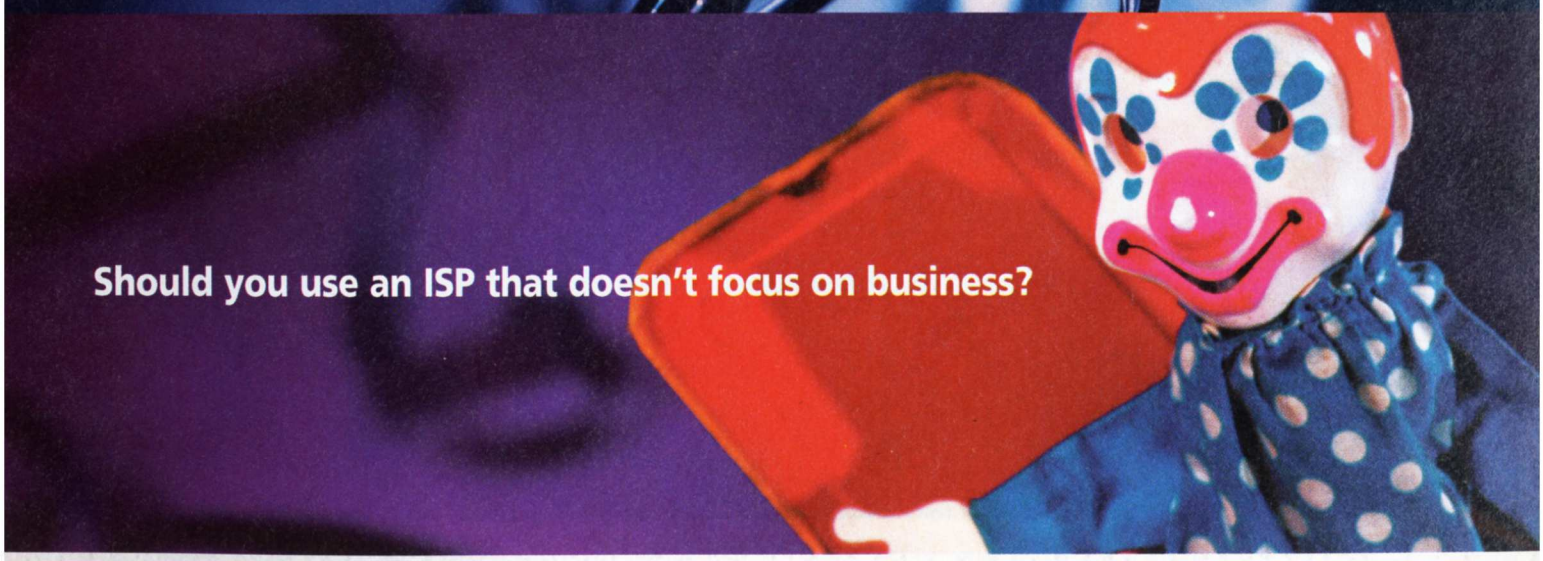
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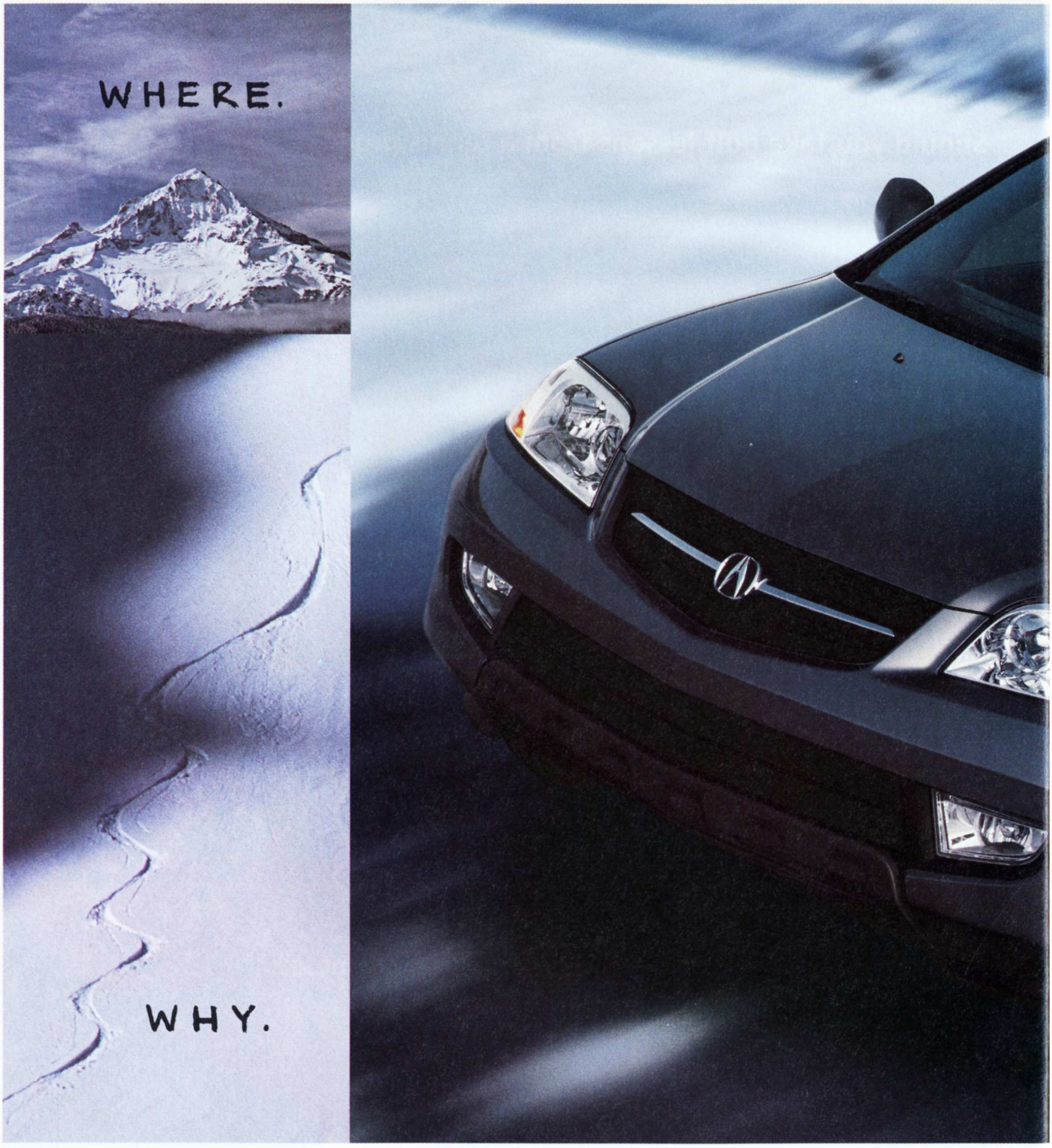


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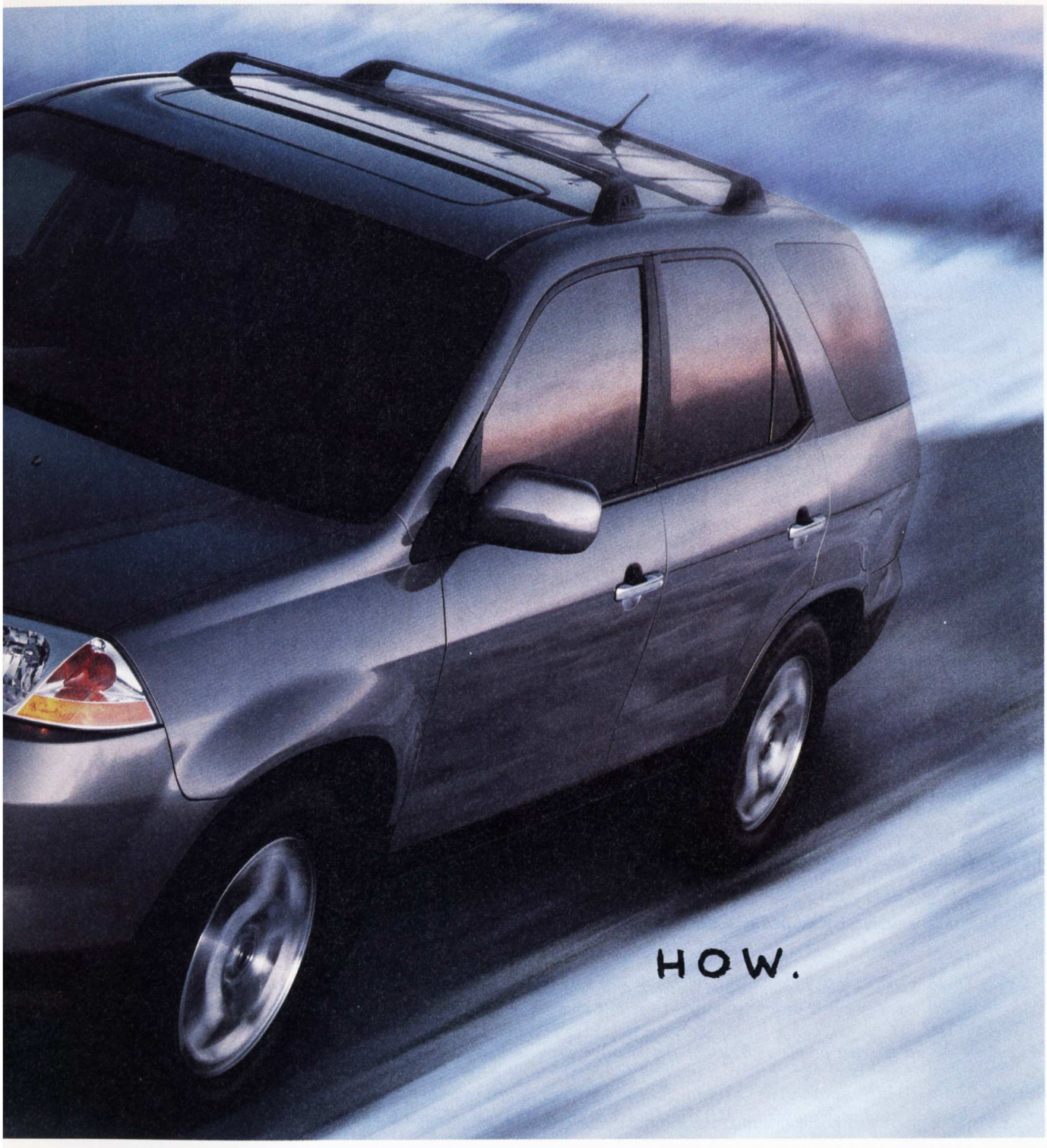
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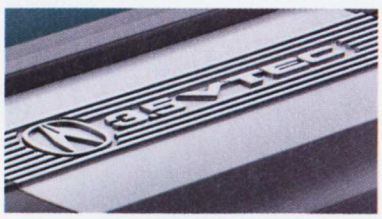
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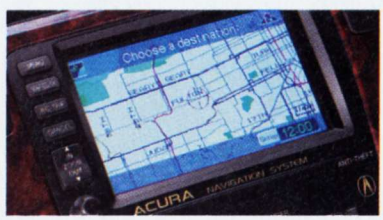
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VOICES *Contributors to Our Pages*

When *TR* Contributing Writer **Steve Ditlea** witnessed robotically assisted heart surgery for his article "RoboSurgeons" (p. 74), he had more on his mind than simply getting the facts straight. "I was sure I was going to be queasy from the blood," he recalls. He wasn't, though. "When you look at the inside of somebody on the screen, it's magnified 10 to 20 times, and blood doesn't even look like blood. The patient's skin is covered with an iodine solution so it doesn't look like flesh, and they're wrapped in plastic to keep them from getting infections. It abstracts what the patient looks like, and I felt no queasiness at all. Instead, I was fascinated."


DITLEA

Ink, not blood, was flowing when **Stephen Mihm** went to investigate the work of MIT Media Lab researcher Joe Jacobson for "Print Your Next PC," p. 66. The special nanocrystal ink could enable ordinary people to stamp their own semiconductor chips—breaking the manufacturing monopoly currently held by billion-dollar semiconductor chip factories. Mihm was particularly impressed by the simplicity of Jacobson's "desktop fab": "The stamps they use don't look all that different from the stamps that you press into an ink pad at the post office to mark something 'first class.'" Mihm is producer of the Web version of *The New York Times Magazine.*


MIHM

When Toronto-based freelancer **Peter Fairley** turned the ignition key in a battery-powered pickup truck at Ford Motors in Detroit, Mich., it was so quiet, he thought he'd done something wrong. But he hadn't. "Because the noise and the vibration weren't there, it was hard to convince myself that it was running," Fairley says. And it's not just quiet: "You can blow away anyone on the road, accelerating from a red light. You realize how sluggish your internal combustion engine is." The fuel cells described in his article "Fill 'er Up With Hydrogen" on p. 54 "have the potential to deliver that silent, zippy ride of the battery-powered car and the range of the internal-combustion engine, without generating much pollution," says Fairley. "That's what everyone's so excited about."

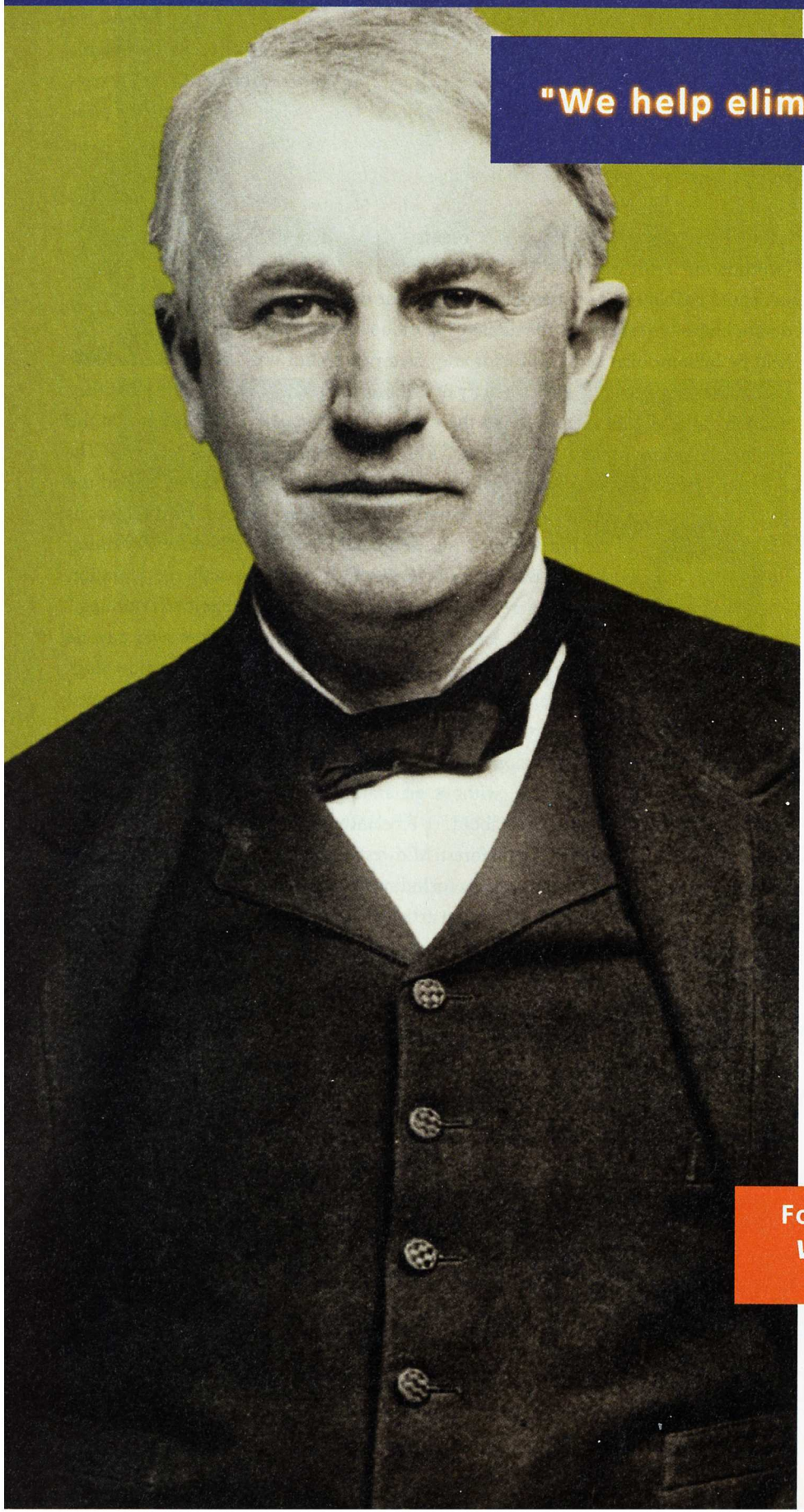
Freelancer **Kathryn Brown** has written evolution stories set in the tropical rain forest, Midwestern ponds and the California desert for magazines including *Science* and *New Scientist.* But curiosity sparked by an article in *The Economist* about "sex in a test tube" last year led her to discover evolution in perhaps the most remote environment yet: the laboratory. Her feature "Biotech Speeds Its Evolution" on p. 84 tells about "directed evolution," a fast-forwarding of natural processes to create new chemicals in record time. "After seeking out evolution in all those weird, quirky places, it's ironic to find it right on the lab bench," Brown says.


BROWN

Freelancer **Gary Taubes** is well known for debunking science and technology myths, and when a friend started e-mailing him cell-phone horror stories, they had an all-too-familiar ring. "It struck me that I'd seen this pattern before many times," Taubes says, "and that it would be worthwhile to lay out the pattern for other people"—which he does in "The Cell-Phone Scare" on p. 117. He admits he doesn't use his own cell phone much, "not because of technological fears, but lack of motivation." But, Taubes adds: "I'm afraid that as soon as I cancel my subscription, I'll suddenly find a reason to use it all the time."


TAUBES

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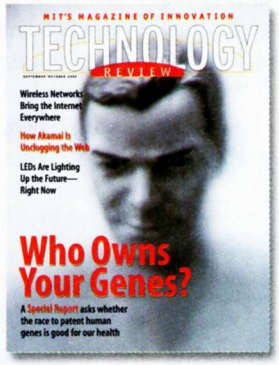
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"Shulman's article is an excellent account of the steps that must be taken to maximize the benefits of genome research."

Who Owns Our Genes?

THE SPECIAL REPORT "WHO OWNS YOUR Genes?" (*TR* September/October 2000) identified critical problems in the rapid privatization of the human genome. Implementation of Seth Shulman's proposals in "Toward Sharing the Genome"—particularly IP-free zones and a moratorium on gene patents—are key to insure that the 50 years of public investment in biomedical research will deliver the promised benefits to people in need. The first step is to set aside the administrative decision by the U.S. Patent and Trade Office—made without any public input process—to grant gene patents. Congress then will need to establish clear public policy and explicitly exclude genes from patenting.



Thousands of citizens have already signed a "No Patents on Life" petition calling for exclusion of genes from the patent system; readers interested in joining this effort can find the petition at www.gene-watch.org.

JONATHAN KING
Professor of Molecular Biology, MIT
Director, Council for Responsible Genetics
Cambridge, MA

SHULMAN'S ARTICLE IS AN EXCELLENT account of the benefits of human genome research and of the steps that must be taken to maximize its benefits to humankind.

The "Bermuda principles" agreed upon by members of the Human Genome Project in 1996 stated clearly the necessity for immediate data release and absence of patenting on sequence per se. The principles have received approval from most of industry and from the great majority of citizens, because they provide a sound basis for wealth creation and progress in healthcare, and they accord with the ethical standards that most people share.

International standards must now be established, or corporations simply will move capital and jobs from one nation to another to best satisfy their business needs. Only by international agreement can democratic standards be maintained.

JOHN SULSTON
The Sanger Centre
Wellcome Trust Genome Campus
Cambridge, England

AS THE PARENT OF A CHILD with Canavan disease, I read the articles on gene patenting with great interest. We and other parents of children with Canavan disease gave our DNA—and that of our sick children—solely to help other families like ours and the public at large. Yet Miami Children's Hospital now owns a broad patent on the Canavan disease gene and collects a $12.50 royalty every time a carrier, prenatal or diagnostic Canavan's test is performed in one of its licensed labs. The patent's enforcement therefore restricts access to testing both physically and financially. Wouldn't it be better ethically, morally and clinically if all disease-causing gene patents carried the following exclusion: "shall not be enforced for clinical testing purposes"?

JUDITH E. TSIPIS
Professor of Biology
Director, Genetic Counseling Program
Brandeis University
Waltham, MA

We welcome letters to the editor.

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Letters may be edited for clarity and length.

Stanford of the East

DAVID FREEDMAN'S "THE MEDIA LAB AT A Crossroads" (*TR* September/October 2000) is a delight for me to read 15 years after I wrote *The Media Lab*, a book about the Lab's first year of self-alignment. The MIT research model of climbing in and out of bed with business (and government) has for decades been so successful financially and intellectually that my alma mater, Stanford, would these days be better styled as the MIT of the West rather than its once arch claim to being the Harvard of the West. Back in the 1950s and 1960s, Stanford provost Frederick Terman created Silicon Valley and its dense interaction with the university by applying what he learned as a visitor at "commerce-tainted" MIT.

Now the option economy of the West Coast mirror image may be affecting the East Coast original. The inherently mercurial nature of "media" research probably requires a much more chance-taking rate of structure change. To stay near the front of a fast-evolving set of interacting technologies, you have to evolve your research organization to match their hectic rate, tapping into their financial metabolism. Chances are good that the Media Labs, plural, will be a portfolio worth investing in.

STEWART BRAND
The Long Now Foundation
San Francisco, CA

AT THE MEDIA LAB, TECHNOLOGY IS AT the core of most of our work, yet there was little technology in Freedman's article. Those readers who are more technology-inclined may want to pick up *IBM System Journal*, vol. 39, nos. 3 and 4, a double issue that features over 25 articles by Media Lab faculty and students.

WALTER BENDER
MIT Media Lab
Cambridge, MA

Broadcast Views

YOUR RECENT ARTICLE "WHO REALLY Invented Television?" (*TR* September/October 2000) conveys the impression that, but for the ruthless monopolistic practices of RCA's chief David Sarnoff, inventor Philo Farnsworth's image dissector would have prevailed over Zworykin's iconoscope. But from an engineer's point of view, the latter was

superior. Farnsworth's image dissector, the electronic equivalent of its mechanical predecessor, the Nipkow disc, created a rather noisy video signal and required very bright illumination. Zworykin's iconoscope, which used the principle of charge accumulation, was thousands of times more sensitive. All image pickup devices developed in the 60-odd years since then have used the principle of charge accumulation; your home video camera would not be possible without it. There can be little doubt that Sarnoff wielded a great deal of power, but in the case of the image pickup tube, he clearly picked the better horse.

ROBERT ADLER
Consultant
Northbrook, IL

WHILE SCHWARTZ CORRECTS THE POPULAR myth that RCA invented television, he spreads a revisionist history of Microsoft, claiming "Microsoft used the infrastructure of Windows to propel its Office software to dominance." Rest assured, if that were true, it would have been used in the case against Microsoft. As a programmer on the WordPerfect team for five years, I saw Microsoft Office beat us fair and square by being the first completely integrated suite of applications on both Windows and the Mac, and not through any underhanded leveraging of "Windows infrastructure." The Justice Department came digging for dirt, but none of us could point to anything devious that Microsoft did. Microsoft's professionalism persuaded me to join the company.

RICKY LOYND
Research Software Development Engineer
Microsoft Corporation
Redmond, WA

SCHWARTZ'S COMPARISON OF FARNSworth to Netscape in its battle with Microsoft is misleading. Netscape didn't invent the Web browser; it was invented at the National Center for Supercomputing Applications at the University of Illinois in Urbana-Champaign.

MATTHEW H. BATTLES
Palo Alto, CA

SARNOFF'S OVER-PROMOTED WORLD'S Fair TV broadcast in 1939 was not the world's first. On February 5, 1937, the BBC began high-definition TV transmissions receivable by the general public on sets produced by 10 different companies, purchasable at retail stores. By 1939, 20,000 households around London were already veteran viewers of live TV every night.

HORACE T.E. HONE
Palm Coast, FL

Pearls Before Swine

HENRY JENKINS' TREATMENT OF ELECtronic games as a new art form ("Art Form for the Digital Age," *TR* September/October 2000) is a refreshing alternative to the crude attacks designers like me have come to expect from everyone. Most worthwhile art is popular in its origins and impulses. Certainly Shakespeare wasn't out to entertain the army of scholars who now dissect his work with such minute attention—he just wrote hits, many ribald and bloody!

The MIT Press

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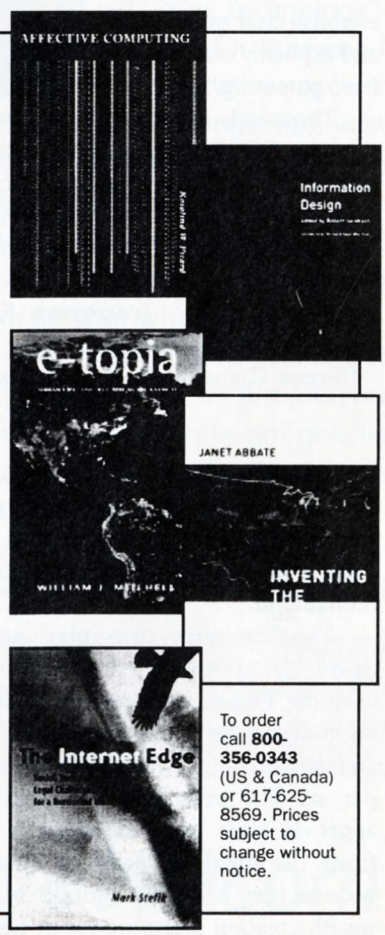
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HAL BARWOOD
LucasArts Entertainment Company
San Rafael, CA

JENKINS IS RIGHT THAT VIDEO GAMES are due some critical perspective. But in looking at games critically, it is good to remember that games are entertainment, and as with all forms of entertainment, they can be "art," or merely entertaining. In the game world, a game that is incredibly addictive and perfectly designed, like Solitaire, is just as great as something that strives for beauty or meaning. To some people, creating "fun" is an art form in itself.

DAVID WALLS
Director of Fun
games.com
Beverly, MA

JENKINS IS ABSOLUTELY CORRECT IN HIS comparison of early film to video games. Game reviews frequently use comparisons to cinema as a measure of a game's success in story and design. But within the decade, comparison to film or television will become moot because technology is changing the definition and face of entertainment. If game developers are wise, they will see their product as the most compelling and efficient form of interactive entertainment to date. If they just mimic film, they are in danger of limiting their audience.

GEORGE SUHAYDA
Senior Art Director
Sony Pictures Imageworks
Culver City, CA

Corrections: The article "Lying With Pixels" (*TR* July/August 2000) mistakenly credited the company Princeton Video Imaging with creating the virtual first-down lines in Super Bowl XXXIV. In fact, a rival company, Sportvision, created those lines.

"Who Really Invented Television?" (*TR* September/October 2000) said the 1936 Olympic Games were broadcast live from Munich; that year, the Olympics were held in Berlin.

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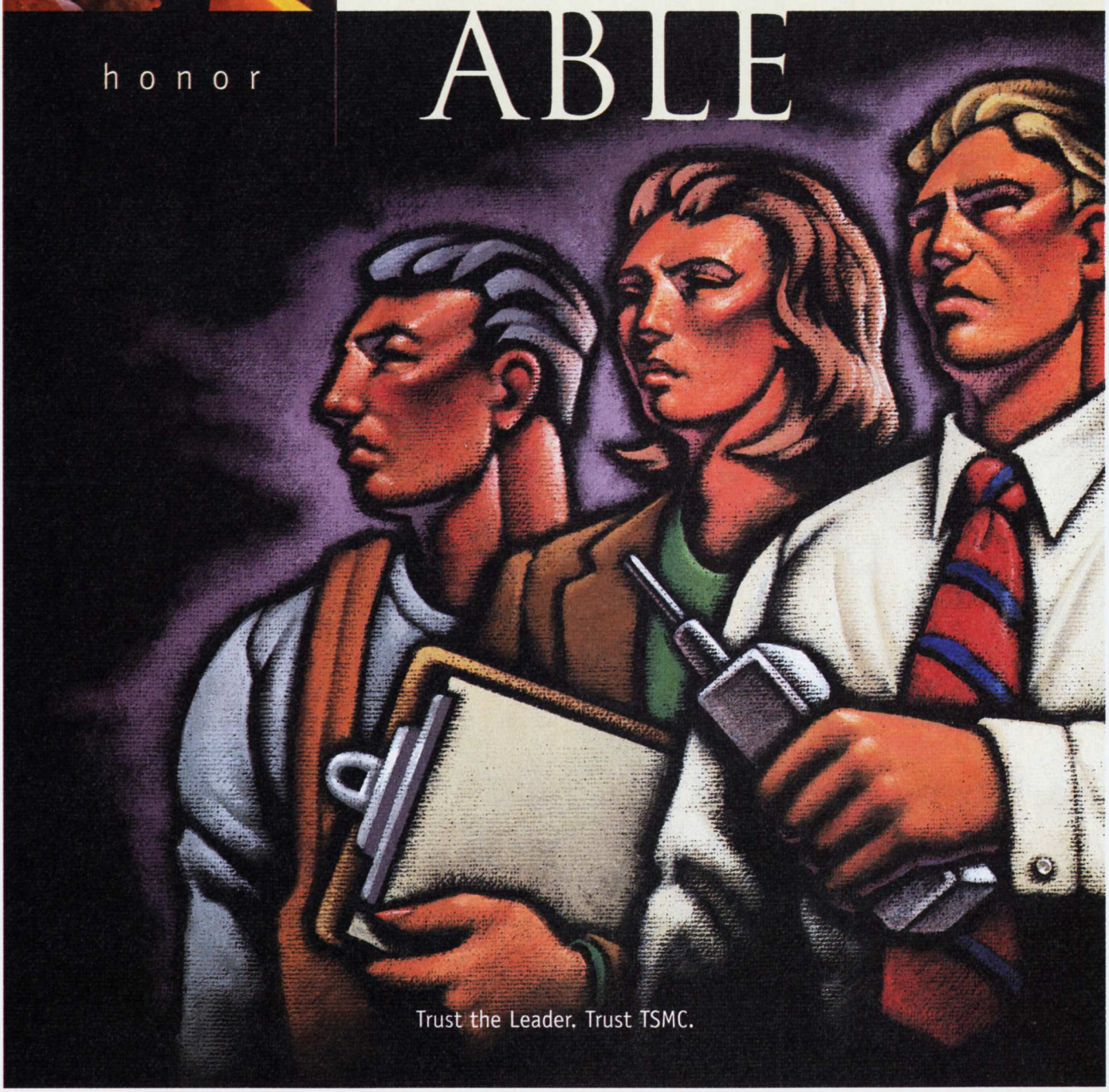


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VITO ALUIA

Insect Antifreeze

A few years ago, researchers kicked up controversy by proposing to create frost-resistant strawberries by spiking the plants with fish genes—specifically, with the gene for making a protein that helps fish survive in frigid water. While activists reacted strongly against the idea, the real problem was that the scheme just didn't work, because the fish protein didn't lower the fruit's freezing point enough. Researchers have now turned elsewhere in the animal kingdom for plant-defrosting genes with better results. Biologists at Queen's University in Ontario and the University of Alberta have deciphered the structure of two insect "antifreeze proteins" that are up to 100 times more active than the fish proteins.

With the structure of the natural proteins in hand, the researchers hope to create artificial versions that are cheaper and easier to produce. If it all works out, the first application may be to help preserve transplant organs longer by keeping them colder. Next could come frost-resistant produce and smoother ice cream. The researchers say they are working on licensing agreements with several agricultural biotech companies.

Sugar Tongue

For diabetics keeping tabs on their blood sugar level, life is punctuated with painful needle sticks. A study by chemists Gary Small of Ohio University and Mark Arnold of the University of Iowa gives the promise of the first non-invasive test. The researchers shone infrared light onto the tongues of volunteers and measured how much came out the other side of this blood-rich appendage, noting a correlation between blood glucose level and the amount of the infrared light absorbed. Developing a practical home instrument is next. Small says a $500 monitor the size of a portable CD player that targets the ear lobe could be available in three to five years.



CERLSOUND GROUP

Tapping into the musical continuum.

Sliding Scale

Imagine a keyboard that could deliver not just the standard 88 notes, but the infinite array of tones between them. That's the idea behind University of Illinois researcher Lippold Haken's "Continuum Fingerboard."

Although the performer sits at the device much as he or she would at a keyboard, that term is a bit of a misnomer—there are no keys. Instead, fingers move along a smooth red cloth, under which lies a row of 256 rods mounted on springs. Pressure to the surface depresses the rods, the movement of which is monitored by tiny magnetic sensors. Sliding your fingers sideways along the board produces any pitch you want, as with a violin. Moving them front to back affects the brightness of tone, and varying the pressure alters loudness. Haken has built a half-dozen of the fingerboards and doesn't see mass popularity in the near future. "It's very difficult to play," he says.

All About Eve

Internet shoppers who have no salespeople to question often abandon their shopping carts—a vexing problem for e-tailers. Sunnyvale, Calif., EGain, a specialist in online customer service, hopes to create a completely different user experience with its interactive "chatterbot"—the EGain Assistant. The assistant consists of a conversational interface with an "avatar," in this case an actress's face that has been photographed in an array of expressions. If a shopper expresses frustration over an inability to find a product, the avatar, "Eve," appears sympathetic and leads the confounded surfer to the information desired. If she can't understand a request, Eve looks puzzled and asks questions until she figures out what the user wants—or determines that she can't provide the answer. When she deems it necessary, Eve turns questions over to human customer service. EGain is developing assistants for several online merchants.



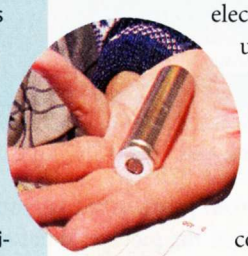
EGAIN

Internet shopping got you confused and frustrated? Ask empathetic "Eve" for help.

Better Battery

Flick on a cell phone or a laptop computer and you're probably drawing power from a lithium-ion battery. They are lightweight and rechargeable, but the material is expensive and toxic. Those problems, which don't much matter for small cells that juice portable electronics, could become a huge headache as auto makers look to large lithium batteries to power electric cars.

A team of researchers at Brookhaven National Laboratory led by chemist Hung Sui Lee has developed a boron-based additive that lets them use a cheaper, less toxic lithium salt in the batteries. This salt, lithium fluoride (LiF), has not been an option until now because it does not dissolve well in the organic solvents used in the batteries. The boron compound helps LiF break apart into ions that can carry charge. Several companies—including lithium battery-maker Gould, based in Eastlake, Ohio—have expressed interest in licensing the technology. If development pans out, the new batteries may be on the market in two to three years.



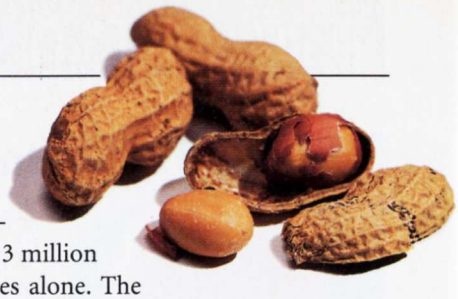
Boron brings a cheaper, safer power cell.

BROOKHAVEN NATIONAL LABORATORY

Power Miser Chips

Adding complexity to portable electronic equipment usually means an increase in power consumption. Now PicoDyne, a semiconductor startup in Albuquerque, N.M., promises more complex, higher-performing electronics that use far less power than standard electronic devices. Most of today's chips run on three volts. PicoDyne, using technology licensed from the University of New Mexico's Microelectronics Research Center, has designed a chip that runs at a much lower voltage and thus consumes 50 to 100 times less power, says company president Earl Fuller. PicoDyne's chips could save power in a range of equipment, including laptop computers, personal digital assistants, mobile phones and digital hearing aids. Fuller expects PicoDyne to introduce its first product, a digital signal processor, by year's end.

Nuts to That

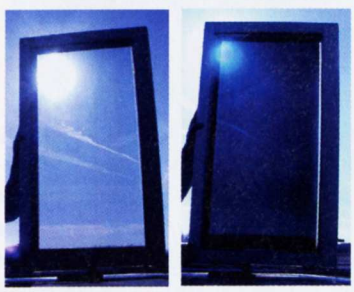


VITO ALUIA

Severe, even life-threatening peanut allergies afflict 3 million people in the United States alone. The only protection now available is to avoid peanuts and their derivatives. While it's easy to eschew peanut butter sandwiches, who's to know if the chips at the office party were fried in peanut oil? Houston-based Tanox has begun human testing of a once-a-month injection to protect the peanut-averse from accidental exposure. The drug, Hu-901, is an antibody that blocks the immune reaction responsible for swelling and itching. People taking it probably won't be able to eat nuts daily, but they should have more time to get help if they do eat those chips.

If Hu-901 is effective in preventing peanut allergies, Tanox may investigate its use against other food allergies. The company hopes a similar antibody to treat seasonal allergies and asthma will get regulatory approval by mid-2001.

Electronic Window Shades



SAGE ELECTRONICS

Lights out: daytime turns to darkness at the flip of a switch.

Long a lab curiosity, "smart windows"—energy savers that darken in response to an electric current—appear headed for U.S. commercial production in the fall of 2001. Sage Electrochromics of Faribault, Minn., has teamed with 3M and the Center for Ceramic Research at Rutgers University to develop a process in which five thin layers of ceramic, totaling only one fiftieth the thickness of a human hair, are baked onto glass panes. Application of electricity to the coating causes the window to tint; the higher the voltage, the darker it gets. Turning the dimmer knob all the way causes the window to block up to 95 percent of light. Similar glass has been used in automotive rearview mirrors, but there have been obstacles to high-volume production of large panes suitable for homes and offices—obstacles Sage says it has now overcome. The glass was developed with $3.5 million from the National Institute of Standards and Technology's Advanced Technology Program.

Grab That Image

Lots of folks, including newspaper photo editors, like to be able to take still photos from video footage. Until now, that's been a blurry, messy business. Salient Stills, a Boston-based company, has overcome that problem with a system that takes video from cable, satellite or videotape and turns out images comparable to high-quality photographs.



SALIENT STILLS

Software takes the blur out of video stills.

The system, VideoFocus, converts every video frame to digital form and displays the frames sequentially on a computer screen. When you select a frame, the system gathers data from pixels in the surrounding frames and uses the extra information to remove noise and sharpen the picture. What starts out as a 72-dpi (dots per inch) video grab ends up a 200- to 300-dpi picture worthy of printing on the front page. Several news organizations, including *The New York Times*, have started using the system, which evolved from work at the MIT Media Laboratory.

Digital Dibs

Downloading copyrighted images, music, video and documents for free may soon get tougher. Elisar Software, a venture-backed startup in Albuquerque, N.M., has developed software intended to protect digital content from being copied and distributed illegally. Co-founder Greg Heileman says the system, expected to come on the market by year's end, combines three existing protection technologies. One software component encrypts the content for online display. A second component decrypts it for viewing and places the material in a "secure container" that prevents copying. When content is sold, it is marked with a hidden "fingerprint" that enables its usage to be traced. The software works with images, music, text and video, and can be used with standard viewers such as Adobe Acrobat.

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All-nighters in the lab. Caffeine overload in the carrel.



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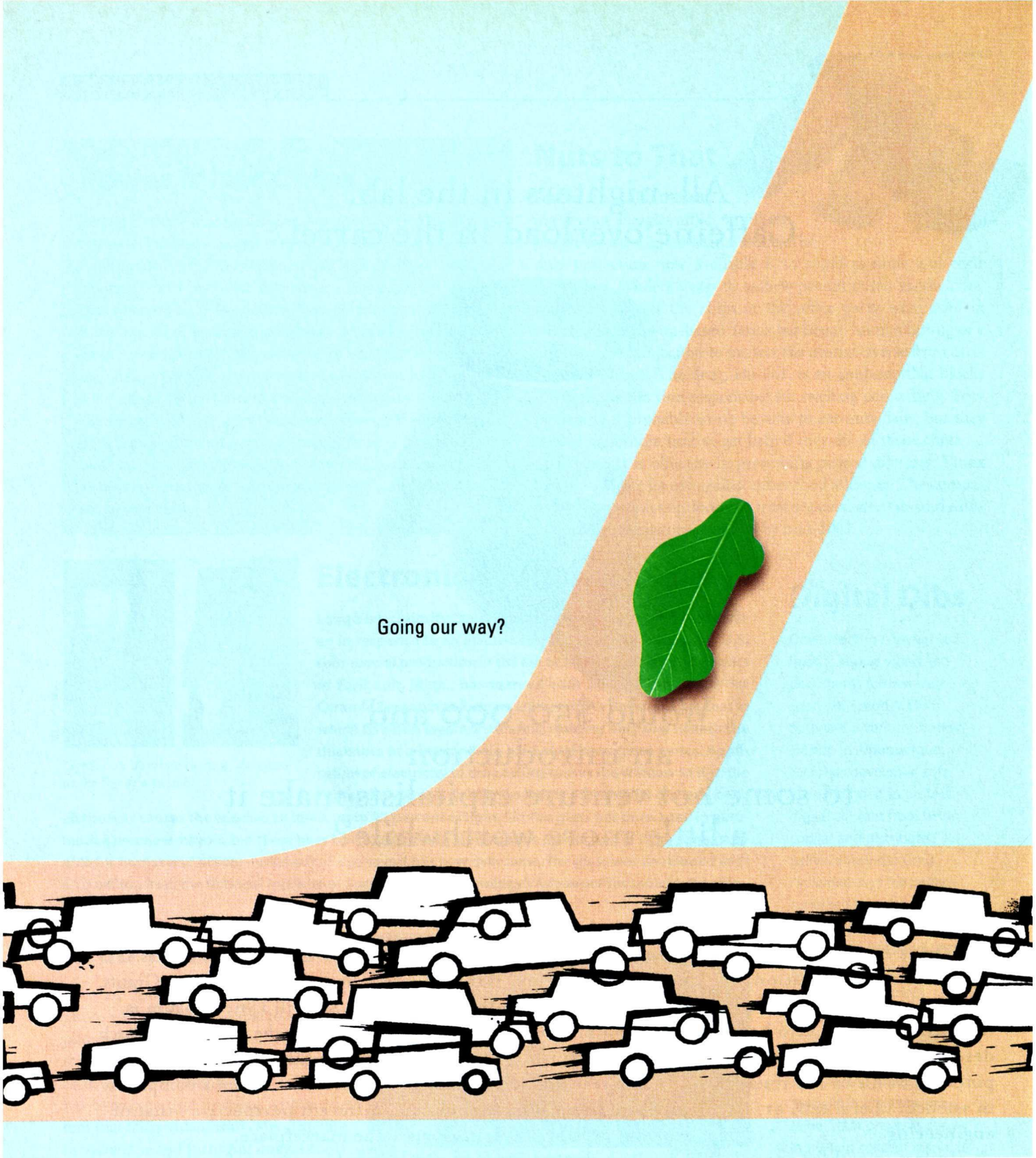
Last year, Islamshah Amlani of Notre Dame took first place with a transistorless digital logic paradigm that could lead to a new era of super fast "quantum computing."

Merrill Lynch Chairman and CEO David Komansky notes, "Through the Innovation Grants, The Merrill Lynch Forum is challenging the academic research community to take a fresh look at their ideas from a completely different perspective—that of the marketplace."

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TODAY TOMORROW **TOYOTA**

Your Work Is Mine!

That's the natural conclusion arising out of the muddled mindset that surrounds Napster and similar Web services, which let millions of people freely exchange their musical recordings. I call it muddled, because it offers all sorts of excuses in support of gratification, while ignoring the central human issue.

I have repeatedly screamed from this column that the "content" of movies, news, books, music and videos that everyone is hyperventilating about is, at 5 percent of the industrial economy, barely one-tenth of the far more important currency no one talks about—information work. The latter represents work proffered by people and machines in medical care, finance, education, entertainment, government, commerce and much more. Information work is huge and will dominate Internet business as it does today's economy.

Imagine now that future Web services would let people freely exchange all this information work, in addition to music. Books, newspapers, magazines and movies in their entirety—not just their online versions—would be first. They would be followed by professional service exchanges, for example of a unique and successful program that helps people identify illnesses from symptoms. Should a gifted doctor go to school for more than 20 years, learn complex skills and work for another 20 years to develop this unique program—so that people can pilfer it without her consent?

No more than you and I can get away with stealing a chair! Advocates of Napster argue that information is fundamentally different from physical objects and should be treated differently. It's true that information does not have a unique physical embodiment and can be easily replicated. Also, it's a lot easier to download music over the Internet than it would be to download a chair…at least during this century. Yet both the chair and the diagnostic program are the result of skilled human work (carpenter or doctor) and capital (woodworking or computing and medical equipment). Here is the key point: Somebody has expended a valuable portion of his or her life to produce a good that other people find beneficial. If the chair maker is compensated for his work by those who benefit from it, so should the program maker be, and the musician.

The low cost of copying software, compared to "copying" chairs, does not change this bigger picture: For centuries, authors, actors, musicians and inventors have been compensated for their contributions based on the same principle: The cost of human work, and of all the economic factors that go into making the good, is spread among the copies (call it tickets, royalties, downloading fees to a Web service or whatever else blows your hair back).

Failing to value the musician's or the doctor's or anyone else's information work will lead us to a society where more than half of human work in the industrial world will no longer be valued! And along the way, we would be demolishing social principles that took us thousands of years to develop, just because we have become interconnected. Are we really ready to surrender the value of human work to this fickle excuse?

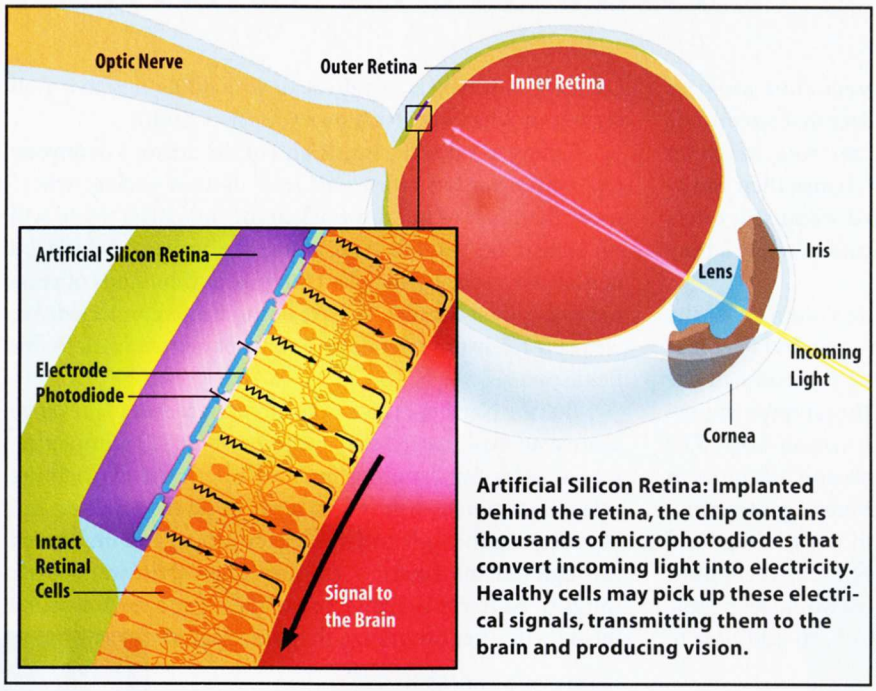
But the Napster crowd offers more reasons: (1) revenge against an exploitative distribution system; (2) stimulating record sales by sampling musical offerings; (3) helping artists disseminate their music, never mind the royalties; and (4) ensuring that our cultural legacy propagates unfettered through free information. Baloney! If an artist wants their songs to be freely available or sampled (or a doctor wants the same for her program), they can elect to put their work in the public domain—rather than adhere to *compulsory* free sharing. If the record companies are greedy, let's just download the music directly from the artists—a new breed of Web services (record companies too, if they are smart) could help with production, distribution *and* fee collection. And if record companies behave illegally, let's prosecute them. But whatever we do or don't do, let's not hide behind such excuses. Stripped of cosmetic explanations, freely sharing information work over the Internet without the consent of its creator is an act of aggression that boasts, "I am entitled to your work for free and for my own precious benefit."



Let's not hide behind excuses. Napster is an act of aggression that boasts, "I am entitled to your work for free."

The central issue here is not an abstract differentiation between physical and information goods, nor a debate on copyright laws, nor a rationalization of the human desire for free benefits. It is the realization that useful information goods, like useful physical goods, involve the same precious ingredient—human life in the form of human work. So let's focus on policies and techniques, most of which we already have, that enable information workers to be compensated for their efforts in accordance with our established principles of social interchange. The privacy, security and payment technologies we need are here. All we need is the steadfast determination to continue valuing human work. ◊

After three years of writing "The People's Computer," and with Technology Review *moving to a monthly format, I bring this column to an end and thank the magazine and my readers. It's been great fun!*



Artificial Silicon Retina: Implanted behind the retina, the chip contains thousands of microphotodiodes that convert incoming light into electricity. Healthy cells may pick up these electrical signals, transmitting them to the brain and producing vision.

BETSY HAYES

NEURAL IMPLANTS

First Bionic Eyes

Blind patients receive replacement retinas

Doctors in Illinois have implanted the first permanent artificial silicon retinas in the eyes of three blind patients. The outcome of the pioneering bid to restore sight using microelectronics isn't yet known, but the undertaking is an important initial step toward realizing the goal of artificially assisted vision *(see "Seeing Is Believing," TR May/June 1999).*

The experiments were led by Alan Chow, a 48-year-old ophthalmologist who is president of Optobionics, the Wheaton, Ill., company that developed the hair-thin vision chips. The prototype devices are 2 millimeters across and contain some 3,500 microphotodiodes. Placed behind the retina, this collection of miniature solar cells is designed to convert natural light to electrical signals, which are then transmitted to the brain by the remaining healthy parts of the retina.

The three patients who received the implants in June—a 45-year-old woman and two men, aged 66 and 74—all suffered from the hereditary disease retinitis pigmentosa, or RP. The illness causes blindness by damaging the eyes' light-sensitive photoreceptor cells, known as rods and cones. "These are all patients with end-stage retinitis pigmentosa," says Chow. "Their vision is almost as bad as you can expect from RP, which is bare to almost no light perception."

Artificial retinas aren't expected to produce perfect vision—far from it. But blind people would benefit from simply being able to tell whether it was light or dark outside, or pick out a person's face across a table. Although the results of the experiments are closely guarded, a press release from the University of Illinois Chicago Medical Center, site of two of the surgeries, stated that "patients may develop some degree of vision over the location of the implant within the next month." Chow says a detailed report of the experiments' outcomes will be published in a scientific journal, probably within the year.

Optobionics' is not the only man-made implant designed to replace damaged photoreceptors. At least three teams in the United States and two in Germany are at work on prosthetic retinas using one of two basic concepts. A group based at Johns Hopkins University, for instance, is working on an "epiretinal" system that uses a miniature camera mounted on a pair of glasses to capture and digitize images and transmit them to a chip placed on the front of the retina. Chow says his subretinal implant is simpler, requiring no external power or information source other than natural light.

Despite the preliminary nature of the experiments, the stakes are quite high for this rapidly evolving field. Ophthalmologist Mark Humayun, who leads the John Hopkins group, is skeptical about the efficacy of Chow's subretinal approach and is concerned that failure could reflect negatively on all retina chip designs. "If it doesn't work, or causes some problems, [I hope] it doesn't give the field a black eye," Humayun says.

The three surgeries are part of a U.S. Food and Drug Administration-approved safety and feasibility study, which allows implanting the new devices in up to 10 blind volunteers. The primary purpose of the trial is to determine whether the eye will tolerate the implants and to test surgical techniques. So far, Chow reports, the patients have recovered well and are all at home. "None have any discomfort, and so far show no signs of infection or rejection. The implant is staying in position... [and] we are also acquiring quite a bit of information and data about how the implant interfaces with the retina," Chow says.

While time lines are hard to predict, Chow does allow for some optimism, saying that if these initial tests succeed and the device functions, "we're hoping that within four to five years there could be a product out on the market."

—Victor D. Chase

COMPUTER INTERFACES

Rounding Out Displays

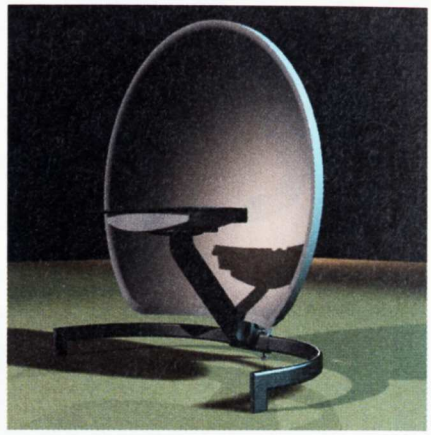
Wraparound screens close in on 3-D

Visitors to domed special-venue movie theaters have experienced the heightened sense of involvement when images are beamed onto the huge concave screens overhead. Now two computer-imaging firms are looking to bring the curved display down to earth—ultimately all the way down to our desktops.

With a price tag of $37,995, the conCAVE from Fakespace Systems of Kitchener, Ontario, is hardly an impulse purchase. But for the high-end presentation market, this immersive 2-D screen offers an alternative to true 3-D displays, which have been limited by the awkwardness of stereoscopic glasses or the expense of surrounding the viewer with screens. The Fakespace display consists of a concave screen with a silo-shaped profile. Meant to be viewed by up to 12 people at once, the screen is nearly 2 meters across and 70 centimeters deep.

Also making its debut is VisionStation, an immersive display developed by Cary, N.C.-based Elumens. Resembling a posh 3.3-meter-diameter TV satellite dish, VisionStation provides a 180-degree view of a scene instead of a typical flat screen's 60 degrees of coverage. "You really see the difference in a driving simulator, when you stop at an intersection and you can look out your car windows from shoulder to shoulder," says Ray Idaszak, Elumens' cofounder and chief technology officer.

Incorporating a 180-degree projection lens and spherical projection software, VisionStation starts at $20,000, still a bit of a reach for architectural and real estate firms that could benefit from virtual walkthroughs for clients of would-be or actual buildings.



ELUMENS

The VisionStation display gives a 180-degree view.

In time, Idaszak insists, curved screens "will ultimately be the upgrade path from the 2-D monitors on desktops." For the avid gamer used to adventuring through cavelike spaces, an affordable curved display could prove irresistible. The screens would also finally do justice to the growing number of Web sites playing host to 3-D environments for interactive chat and shopping.

—Steve Ditlea

FUEL CELLS

Wireless Feels the Power

As more and more portable electronics go "wireless," at least one component of the technology is struggling to keep up with the advances: the power source. As any user of wireless wonders knows, you still need to periodically plug the batteries into a bulky recharger—or simply throw them out. Polyfuel, a tiny spinoff from Palo Alto, Calif.'s SRI International, could change all that with a scaled-down version of the same fuel cells being developed to power cars and trucks *(see "Fill 'er Up with Hydrogen," p. 54)*.



JAMES YANG

Polyfuel's dainty power plants can serve up the trickle of electricity needed to operate a personal digital assistant or cell phone, and the company is promising commercial products within a year that will supply continuous power for five times longer than today's best lithium-ion batteries. "If SRI can make this work then God bless them," says Milosz Skrzypczak, a consumer electronics analyst at The Yankee Group, a market research firm in Boston. "I'll be happy to stop charging my phone every couple of days."

The technology behind SRI's tiny fuel cells is a variant of the proton exchange membrane (PEM) cells slated for automobile engines. But unlike the PEM cells used in cars, these smaller versions consume methanol rather than hydrogen gas; as a result they can be refueled quickly and inexpensively. Pop in a cartridge of concentrated methanol the size of an AA battery, and these electrochemical devices could, in principle, deliver juice for up to two weeks of phoning.

Motorola and Samsung are working on similar tiny fuel cells. But Polyfuel plans to beat the electronic giants to market, beginning production of a million fuel cells a month by the end of 2001. "We want our technology to be very transparent to customers," says Subhash Narang, director of product development for SRI's physical sciences unit. "The only difference is that they'll never have to plug into an AC outlet and won't have to carry a charger."

Consumers will still have to come back to purchase proprietary methanol cartridges designed to keep the poisonous fluids in their place. Like razor blades, these disposables could even be more profitable than the devices they serve.

—Peter Fairley



LUCENT TECHNOLOGIES

From left to right, the images show the progressive reconstruction of a virtual object using new data compression software for 3-D graphics.

DATA COMPRESSION

3-D Over the Web

Send your body scan to the virtual tailor for a perfect fit

THE ABILITY TO QUICKLY AND RELIably transmit 3-D images over the Internet could make everything from shopping for real estate to playing video games a lot more "real." Imagine clothing companies transmitting 3-D body scans of their customers to a factory where tailored goods are made and shipped directly to the customer. Real estate firms could offer sophisticated virtual tours of homes on the Web, where a potential buyer could "walk" into a house, move furniture around and even tear down walls.

But for the average Web user with a 56K modem, downloading complex 3-D images off the Internet remains cumbersome, with long delays and unexpected crashes. To make 3-D virtual objects more widely available on the Internet, a team of researchers from Lucent Technologies' Bell Labs and Caltech have demonstrated a way of compressing "digital geometry" that allows 3-D data to be downloaded much faster and more efficiently than is possible with current standards.

Compression of video and audio, squeezing digital data into as few bits as possible, has become commonplace on the Web. But the same compression tricks that work so well for audio and video don't work nearly as well for geometry, which involves huge and complex data sets. "Geometry is already appearing in many different places on the Internet right now and will eventually become available on a broad basis," says Peter Schröder, one of the researchers involved in the project and a computer scientist at Caltech. As the demand increases, so will the need for sophisticated tools for transmitting the information over the Net.

Schröder and Bell Labs' Wim Sweldens (one of the *TR100*) tackled the problem by designing a mathematical technique using "wavelets"—a fancy way of processing the millions or billions of triangles used to describe a three-dimensional shape. MPEG-4, the latest standard on the market for deploying multimedia content over the Web, sends all the information in one shot. In contrast, the new method transmits information progressively. For instance, when downloading a 3-D representation of a person's head, the most important information, like the rough shape of the head, arrives first, followed by the finer details such as the shape of the eyes and nose and the texture of the hair. Tests have shown that this method takes one-twelfth the time of MPEG-4.

"They seem to have finally crossed the threshold for delivering complex geometry over the Net," says Tony DeRose, senior scientist at Pixar Animation Studios in Richmond, Calif.

While the Bell Labs team is looking into the possibilities of commercializing their compression technique, its members declined to comment on when it will be made available. "The technology itself could be deployed in short order," says Schröder. "We have working code, after all."

—Alexandra Stikeman

FOLLOWUP

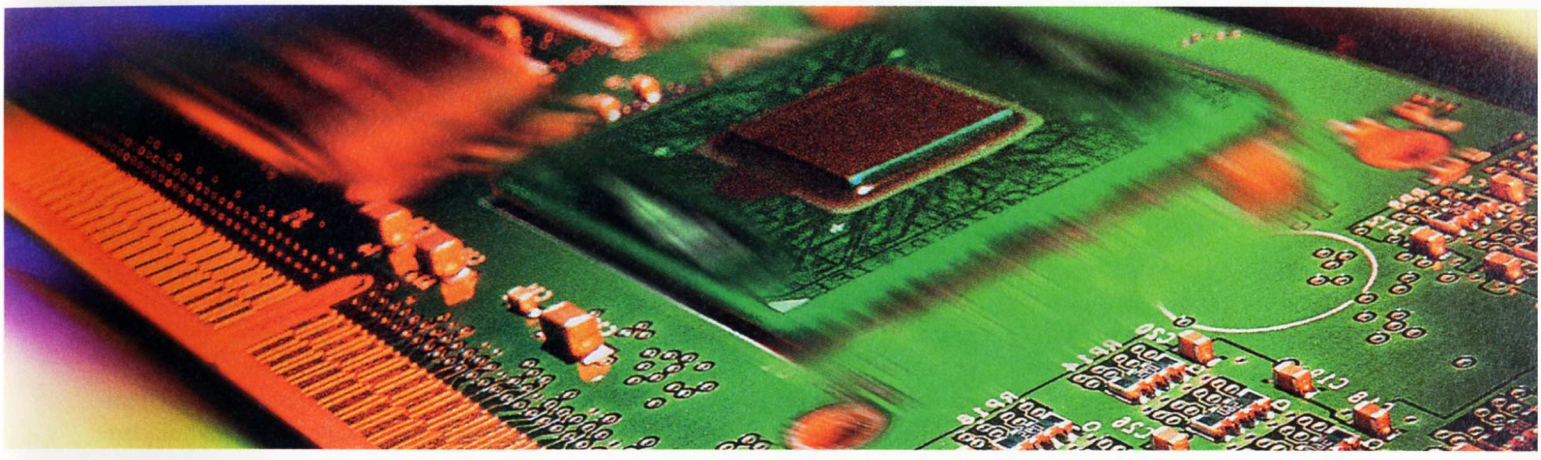
Tomorrow's Transistors

In *TR*'s special issue on the future of computing (*Beyond Silicon*, TR *May/June 2000*), we documented efforts to replace silicon with computers based on quantum effects, DNA and organic molecules. Advances reported in each of these areas in August have brought the technologies closer to reality.

- A collaboration led by IBM Research's Isaac Chuang (one of the *TR100*) created an advanced quantum computer that was able to solve in one step a mathematical problem that requires repeated steps in a conventional computer.
- Chemists at the University of California, Los Angeles made an on/off switch using an organic molecule and predict they will soon have working memory for the molecular computer they are building with researchers at Hewlett-Packard.
- Scientists at Lucent Technologies' Bell Labs and Oxford University reported in the journal *Nature* that they had built a minuscule motor out of DNA, work that could one day lead to the nanofabrication of functioning computers.

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PHOTONICS

Blazing Data

Could a "perfect mirror" replace fiber optics?

TWO YEARS AGO, MIT GRADUATE student Yoel Fink built the "perfect mirror"—one that reflects light from all angles with negligible absorption. Now OmniGuide Communications, the Cambridge, Mass.-based startup Fink helped found, hopes to roll that perfection into cable that can carry light of higher intensity and a broader bandwidth, transmitting up to 1,000 times more data than fiber optics.

"Not too far in the future, we're going to bang into the limits" of conventional fiber optics, says MIT materials scientist Edwin Thomas, another OmniGuide founder. In addition to transmitting more data, the new cable could eliminate the need for signal boosters every 60 to 80 miles. And, unlike fiber optics, the cable would have no trouble transmitting light around sharp bends, allowing the cables to be miniaturized to the scale of the tiny optical switches being developed for the optical Internet (*see "The Microphotonics Revolution," TR July/August 2000*).



JOHN JOANNOPOULOS

A computer model of light waves inside OmniGuide's design of a mirror-lined coaxial cable.

"What we are suggesting is really revolutionary, not evolutionary," says MIT physicist John Joannopoulos, the third of the company's founding trio.

The technology is essentially hollow tubing lined with the dielectric mirror first fabricated by Fink, now an assistant professor at MIT. Dielectric mirrors, widely used in photonics, are specialized mirrors with the ability to reflect specific wavelengths of light with near-perfect efficiency. Unlike the bathroom mirror, the dielectric kind is nonmetallic and not conductive, so no photons are lost by exciting electrons in the mirror. Until Fink's "perfect mirror," however, dielectric mirrors could only reflect light from a limited number of angles, allowing the rest of the light to pass through.

So far, OmniGuide has attracted $4 million in venture capital. Recently, the team went a step further creating the first dielectric coaxial cable, combining the benefits of dielectrics with the properties of the metallic coaxial cable your TV uses. For the moment, a commercial coaxial cable remains in the realm of theory, but Joannopoulos says OmniGuide may someday try to manufacture these as well.

—Erika Jonietz

BIOTECHNOLOGY

Fragrant Genes

The explosion in available genetic information is already having a potent impact on everything from medical diagnostics to forensics. Still, you wouldn't think it could change what we taste and smell. Guess again. La Jolla, Calif. startup Senomyx is identifying the genes behind our ability to detect different flavors and odors, hoping to use the receptors responsible for these sensations to help create products such as improved artificial sweeteners and better-tasting antibiotics.

Any given odor consists of one or more airborne molecules, each of which binds to a unique combination of scent receptors, the molecular structures in the nose that help us tell a banana from a rotten egg. Nearly 90 percent of the estimated 350 human receptors have been identified. More than half of this work was done by Senomyx, which is seeking patents on more than 200 of the genes that govern the scent receptors.

Senomyx is developing high-throughput screening methods that will allow its scientists to run thousands of chemicals past the receptors to learn which combination of receptors detects each compound. The company's aim is to pinpoint compounds that bind to receptors in ways the food, fragrance or pharmaceutical industries might find useful: mimicking, blocking or even enhancing tastes or smells.



JAMES YANG

The company is working to do the same for taste receptors, of which very few have been identified. Senomyx cofounder Charles Zucker, a biologist at the University of California at San Diego, identified more than 20 potential bitter-taste receptors last year. Senomyx sees Zucker's discoveries as the source of its first potential products: palatable oral antibiotics and artificial sweeteners without bitter aftertaste, says Lubert Stryer, a Stanford University biochemist and another of Senomyx's founders.

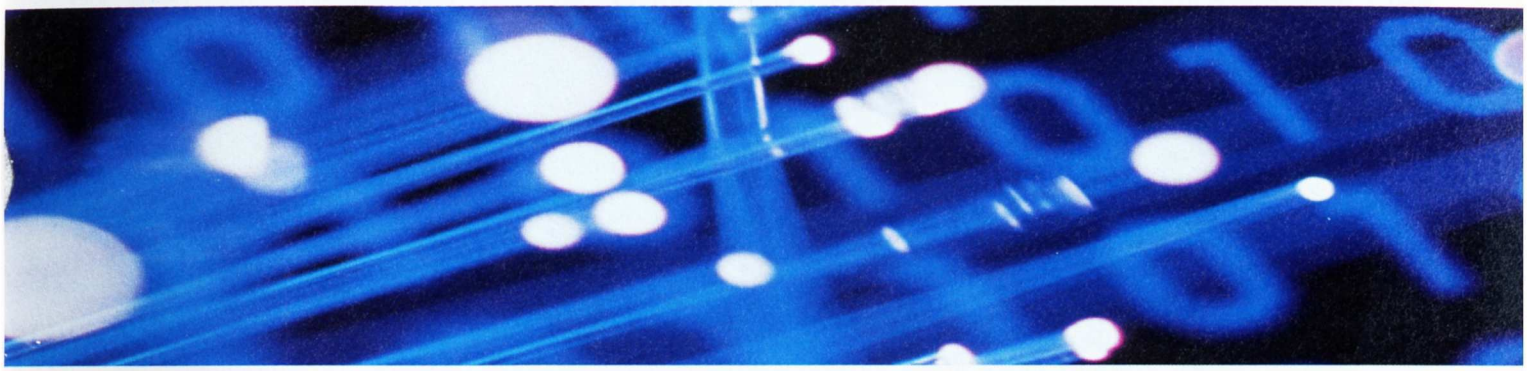
Stuart Firestein, a specialist in scent receptors at Columbia University, finds Senomyx's approach promising: "The science is a bit young, but there is a tremendous amount of potential here."

Even more tantalizing: Senomyx's recent license on a potential human receptor for pheromones, which influence sexual attraction in animals. "We have to take a 'wait and see' approach," says Mark Zoller, Senomyx's vice president of research, about the company's future use of pheromones.

—Erika Jonietz

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Xros June 2000	**$3,250,000,000** Acquired by **Nortel Networks**	NEW FOCUS August 2000	**$462,875,000** Common Stock Lead Manager
CYRAS August 2000	**$150,000,000** Convertible Subordinated Notes Lead Manager	NEW FOCUS May 2000	**$115,000,000** Initial Public Offering Lead Manager

Nowhere does change happen faster than in the optical communications industry (last clocked at 186,000 miles per second). Seeing the future before it happens isn't just an advantage, it's mandatory. And that's why the CSFB Technology Group was chosen to advise on five of the seven largest optical networking M&A deals in history. And to lead-manage more equity financings for optical networking companies than any other firm. The CSFB Technology Group — helping others to see the (value of) light.

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The ABC's of Safety: Air bags. Buckle up. Children in back.





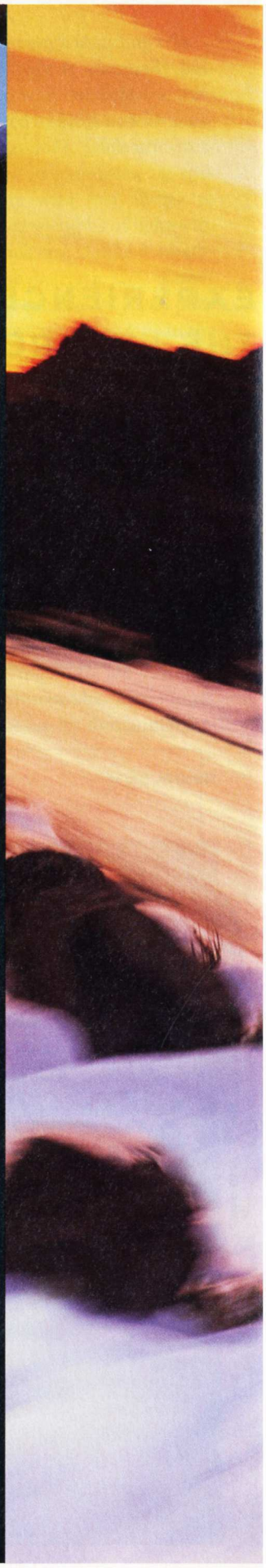


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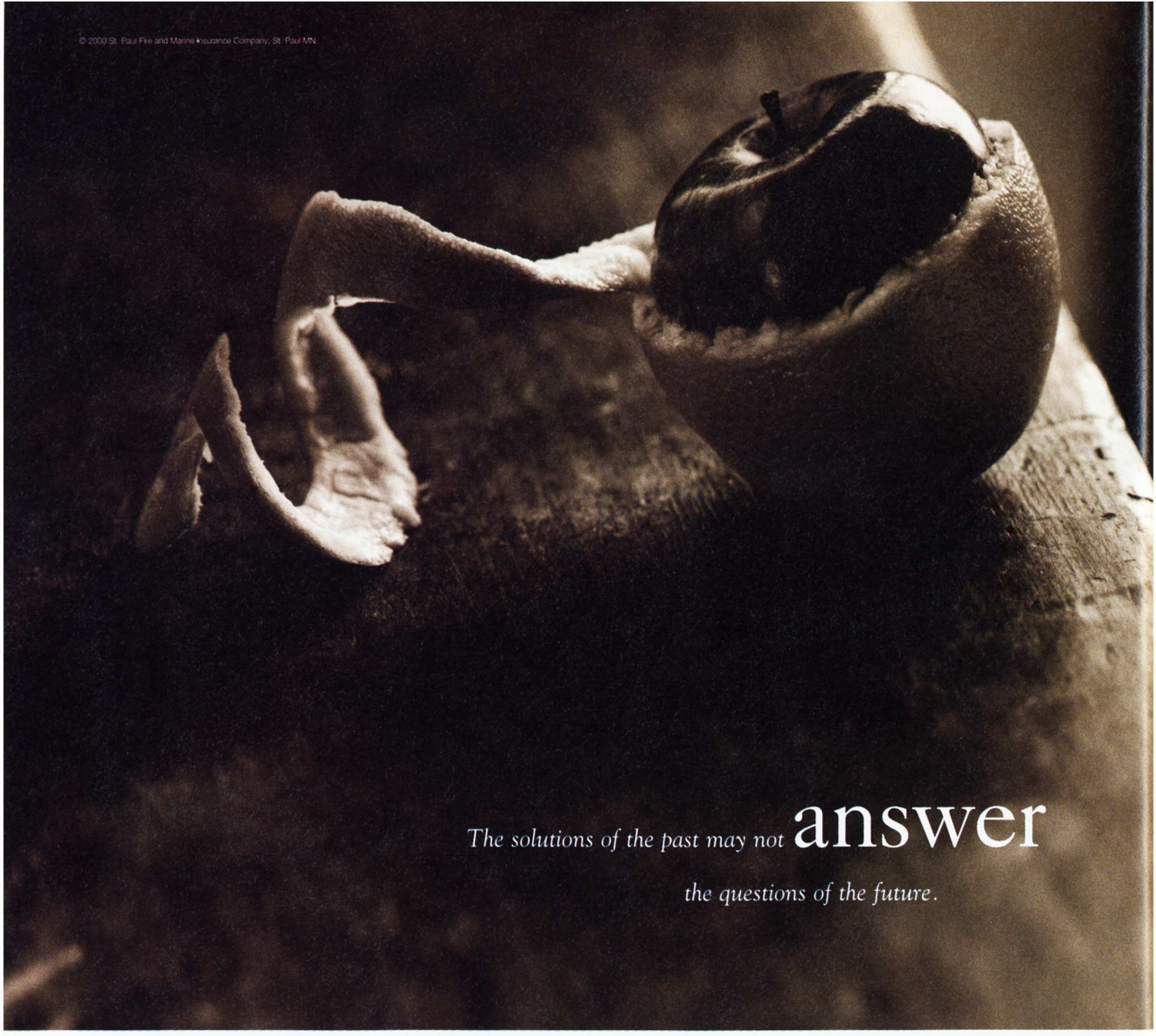
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Less Money, Better Technology

PALO ALTO, CALIF.—THREE-THOUSAND-DOLLAR mountain bikes line the wide sidewalks on this town's main street. His-and-her Jaguars clog public parking lots. The local diner serves $100 bottles of champagne with burgers and fries. Three-bedroom, one-bath "bungalows" rent for $8,000 a month.

Those sound like Hollywood prices, but this isn't Hollywood; it's the heart of Silicon Valley. The stretch of land between here and San Jose to the south remains the world's hottest hotbed for innovators in information technology. Yet today greed defines the life of this place, not inspiration or dedication, and that's troubling.

When I moved to the Valley in 1985, it was a paradise for those, young and old, who wanted to invent the future. These self-styled pathbreakers had trouble tying a tie, and if they bought homes at all it was not to furnish them. Sure, engineers and marketers—the twin pillars of Silicon Valley's wealth—wanted wealth: fair pay and stock options. But the task of "getting it and spending it" took a back seat to "making it," and "it" usually was a thing that worked, a machine with a soul, or at least an innovator with one.

Easy money is ruining Silicon Valley—creating a culture where people cut corners because showing up counts for more now than putting on a good technology show.



Most machines have no souls anymore because their innovators have sold theirs. So much money is pouring into Silicon Valley that the hunger is gone. People don't play for the fun of it, the joy of it, the glory of it any more. University graduates, fresh on the payroll, talk about how quickly they will make their first *10* million dollars. A mere million is no longer cool. Not when a modest tract home in south San Jose—the sort of place a schoolteacher might own in Oklahoma City—costs that much.

No one really knows how the passion for instant wealth will influence innovation. Wealth isn't the enemy of invention, just as necessity isn't always its mother. The history of invention is rife with bold thinkers and brave doers who built great things and never got their just rewards financially. But the other extreme holds now. Any electrical engineer from Stanford or MIT can haul down big bucks and support a lifestyle better suited to Elvis Presley.

Easy money makes the tough choices even tougher for innovators. Easy money creates a culture where people will cut corners because showing up counts for more than putting on a good show.

If this stands, watch out. Innovators in the fields of computers, software and the Internet have been spared the product blowbacks that bedevil other industries—so far. For instance, when Firestone's tires began to fail on Ford cars, people actually died, and Firestone had to replace millions of tires: a grim reminder that technologies do fail regardless of good intentions.

In the world of Internet time and e-commerce, the possibility of disastrous failure has been removed from the lingo and the mindset. The best and the brightest face only "challenges" today, and the worst that ever happens to them is a "setback" for which they are nonetheless rewarded. Failure, in short, no longer humbles innovators. It should. But how can failure humble a multimillionaire, especially one whose riches were built without scoring a hit product or service?

Easy money, I fear, is turning innovators into show horses, ready to jump on command but lacking the character to deal with the inevitable downturns. Sated on riches, obsessed with equity portfolios and charitable donations, high-tech innovators no longer think they need to accept the costs of failure.

We are accustomed to technologies soaring onward, relentlessly delivering the "new and improved," but this is not always the case, and computer innovators will learn this sooner or later, as engineers in the field already have. Someday, the Web world will suffer its own equivalent of the blown tire that led to the grounding of the Concorde. When this happens, will the pooh-bahs of the Internet have the honesty of the British and French officials who revoked the Concorde's flightworthiness certificate? I'm afraid they won't, and one culprit will be undeserved riches, which have made tough choices that much tougher. Less money, better technology. Less money, more inspiration. Less money, more honesty.

Walking down the streets of Palo Alto, dodging the fancy bikes, I catch snippets of overheated conversations and entertain the thought that I am on the wrong side of history. Hey, maybe there's nothing wrong with Dom Perignon and fries. But living well can betray the artist in us all, and savage the rare creator. So in Silicon Valley—and the many boomtowns it has spawned—the inventor who played for glory is a vanishing species. Now they only play to win. And all for the sake of an overpriced bungalow. ◊

This is Zachary's final column for Technology Review. *He thanks his readers and the magazine's staff for their support.*

IP's Middle Child Grows Up

On June 21, lawyers for Microsoft filed an application to trademark a stylish, logolike version of the term ".net." Big deal? You bet. The following morning, the software giant unveiled its new .NET strategy, a "next generation Internet experience" that Bill Gates described as a bet-the-company plan to reinvent the way Microsoft does business. Analysts immediately hailed .NET as Microsoft's most important announcement in years.

Amid the hoopla, Microsoft's trademark application went completely unnoticed by the pundits. That's no surprise, as Trademark tends to be the ignored "middle child" of intellectual property (IP) protection. Trademark's little brother, Copyright, gets all the empathy because he's getting beat up on the Internet by services like Napster. Meanwhile, Patent, the big sibling of the IP family, is stirring up controversies over genetics and online business models. Yet Trademark is often the most successful of the three—quicker than Patent and more powerful than Copyright.

With its new .NET strategy, Microsoft knows that the real power and the big bucks are in building the brand.

Simply put, a trademark grants exclusive rights to a word, phrase, symbol or design that is used to identify and distinguish the goods or services of one party from those of others. That may sound like a funny way to protect technology, but Microsoft knows that the success of .NET depends most of all on winning over the hearts and minds of consumers. Thus, Microsoft's effort to corner the brand names it will soon spend millions making synonymous with the next wave of personal computing. In addition to filing to protect its new .NET logo, the company filed to protect the words Office.net, Exchange.net, Passport.net, Msn.net and Word.net, among others.

Trademarking these names is all the more crucial because, technologically speaking, Microsoft isn't doing anything all that unique here. The .NET effort is based on XML, the Extensible Markup Language, a technology for making any kind of data or content portable among devices as diverse as cell phones, digital TVs, home appliances and previously incompatible computing systems. As such, XML will be a public-domain technology defined by standards bodies and owned by no one in particular.

Even though you can't trademark the everyday use of common words—there are no Cell Phone™ brand cell phones—hardly any term or symbol is entirely safe from proprietary claims, least of all those that embody the promise of the Internet. IBM, for instance, owns the trademark to an @-sign version of the letter "e" and has reserved its use for dozens of categories of e-products and e-services ranging from computing and financial offerings to possible uses as a logo on chocolates and jars of jam. Whereas the U.S. Patent and Trademark Office has rejected every one of the more than 500 various attempts to trademark "e-business," IBM has nonetheless become closely associated with the term thanks to heavy use of its trademarked e-logo in its advertising. Using the same strategy, Microsoft will likely create the impression that it owns ".net."

Globalization has also done its part to magnify the importance of trademarks. Remember when Nike was almost blocked from selling apparel at the 1992 Olympics in Barcelona because a Spanish firm had already trademarked the word "Nike" locally? These days, when a major U.S. company is announcing a new marketing strategy, you can bet its branding effort will be global.

According to Bill Ferron, who has represented Microsoft since 1984 as a partner with the Seattle-based Seed Intellectual Property Law Group, Microsoft has had its share of problems with name pirates and brand squatters both at home and abroad. "In the past, we've had issues because we haven't made the effort to get the filings," says Ferron. The coordinated worldwide launch of the .NET strategy and trademarks, he says, "reflects a more mature strategy."



Sure, patents and copyrights are still important for making sure that people don't steal your inventions or copy your computer code. But Microsoft and IBM know that the real power and the really big bucks are in building and maintaining a brand. Just ask William R. Bradley, a partner with Glankler Brown, the Memphis, Tenn., law firm that represents Elvis Presley Enterprises Inc. To better protect and serve Elvis, the estate in recent years has been on a trademark tear. It first trademarked the name Elvis Presley in the mid-1980s. Then the company trademarked Heartbreak Hotel, first for a licensed restaurant chain, then for use on clothing and drinking glasses. More recently came the trademarks for All Shook Up key chains and Love Me Tender golf balls.

Which brings us to the most remarkable aspect of our neglected middle child and his two siblings. Mr. Patent expires after 20 years. Mr. Copyright also lapses into the public domain after a certain point. But Mr. Trademark is endlessly renewable century after century. Which is why Elvis will live forever. ◊

Evan I. Schwartz, author of Webonomics *and* Digital Darwinism, *holds registered trademarks on both titles.*

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Calgene

After a bench trial in federal court in Delaware that involved Calgene's genetically engineered tomato and Enzo's genetic antisense patents, Hale and Dorr obtained a verdict of invalidity and noninfringement for its client Calgene. That decision was also affirmed by the court of appeals.

Hale and Dorr. When Success Matters.

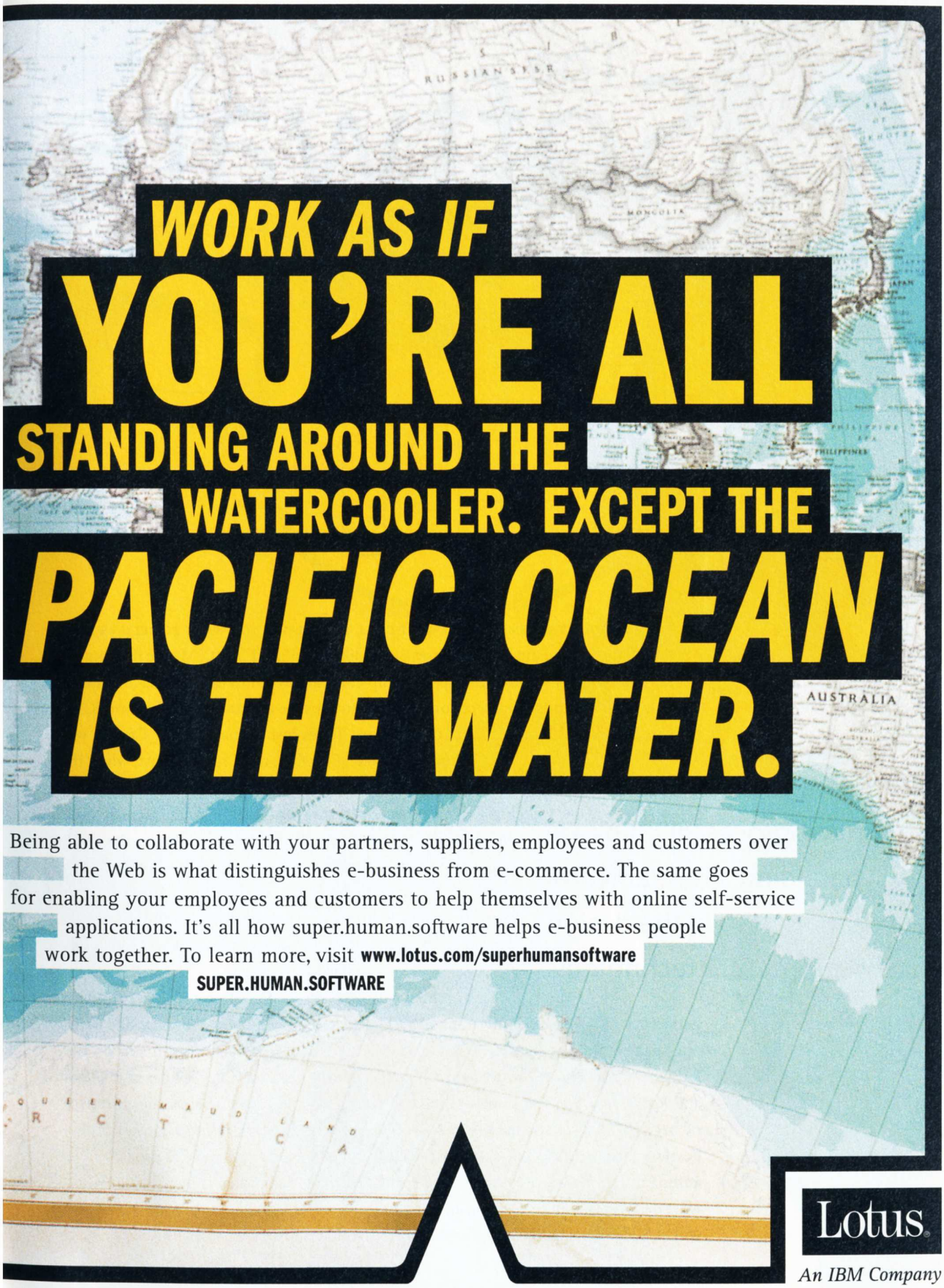
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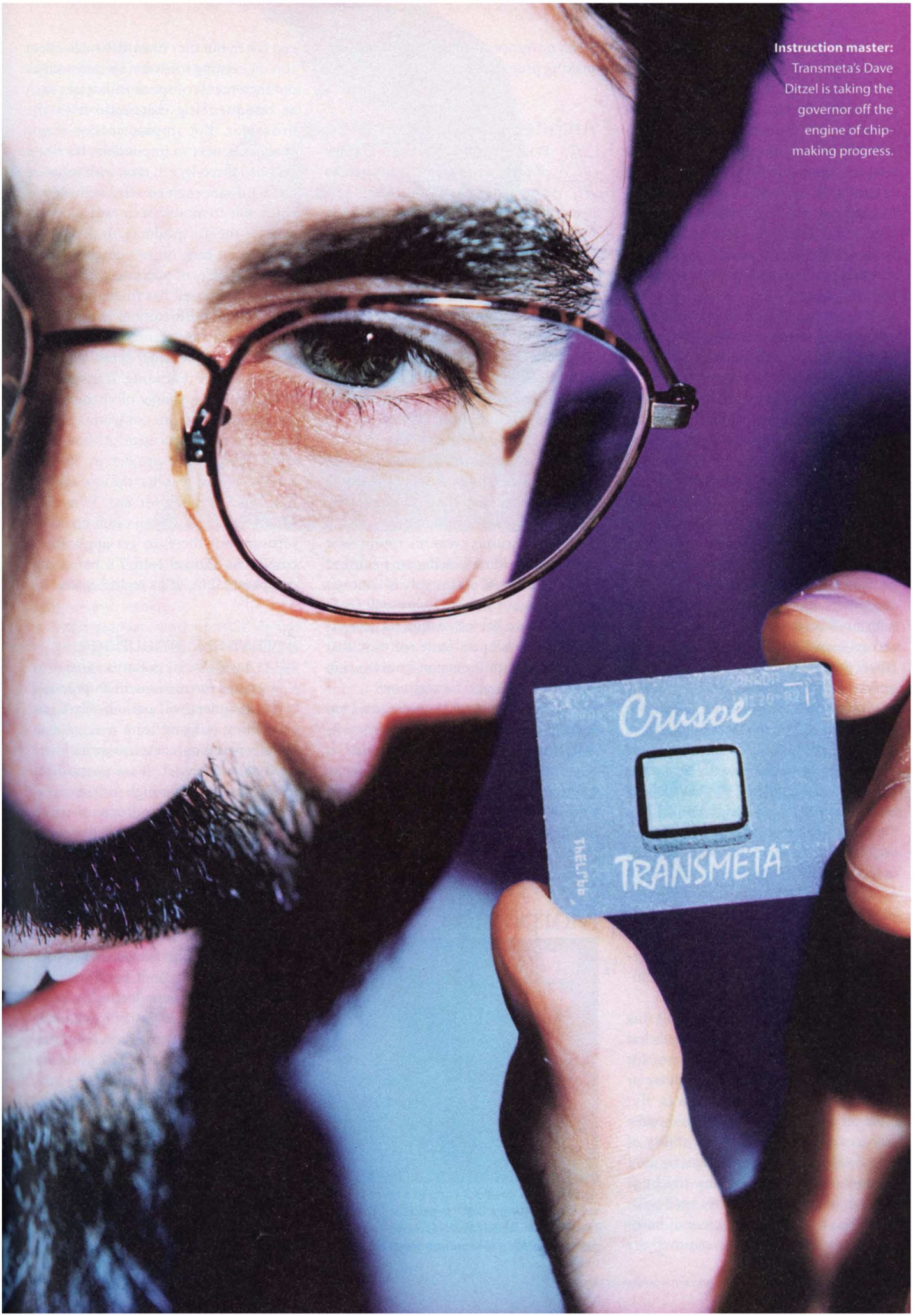
The Software CHIP

Upstart Transmeta's pioneering microprocessor chips are heralding a fundamental evolutionary step in the design of computing's core technology.

WHAT IS IT ABOUT TRANSMETA CEO DAVE DITZEL THAT MAKES YOU WANT TO BELIEVE HIM? Maybe it's the way he unabashedly uses words like "cool" and "neat." Maybe it's because he had the audacity to build his upstart chip company within view of Intel headquarters. Maybe it's because he never completes a sentence, so enthusiastic is he about Crusoe, his company's brand of microprocessors. From last January, when Crusoe was announced in a blaze of fanfare, until mid-August, when the company filed to go public, Ditzel made himself hoarse pushing the Crusoe chip. Whether in front of 200 engineers or a single reporter, his message was unflagging: Crusoe—the Intel-compatible chip with one-tenth the power requirements of a Pentium III—is going to change the world of computing forever. "Crusoe is low-power, it's compatible and it's high-performance," he said in one of a series of interviews held before the August filing. "That's our mantra."

This summer, the company and Ditzel went silent for the quiet period that follows every initial public offering. But by then the Crusoe message had developed a life of its own: Not since the Apple iMac had there been such a fuss in Silicon Valley like the one Crusoe has brought ashore. It's no surprise that Valley insider rags *Upside* and *Red Herring* ran Transmeta as their cover stories last spring, but before the quiet period began, Ditzel was also quoted in *Time, USA Today* and a horde of other consumer publications. Transmeta's publicity efforts have fed in part on the company's hiring of Linux author and open-source software guru Linus Torvalds. Torvalds has been part of the software design team at Transmeta, and has lately been working on a version of Linux that will complement Crusoe's application in the exploding market for mobile devices.

PHOTOGRAPHS BY ANNE HAMERSKY



Instruction master: Transmeta's Dave Ditzel is taking the governor off the engine of chip-making progress.

The IPO itself is a dour, close-mouthed document that reveals little of Transmeta's future design plans, and is instead full of warnings about what might go wrong on Transmeta's road to profitability. Indeed, as of this writing, not a single Crusoe product has shipped in appreciable volume. The company lost $41 million in 1999 and another $43 million in the first six months of 2000; the prospectus makes it clear that investors shouldn't expect to see profitability in the near future.

But it would nevertheless be difficult to find a startup that began more auspiciously, or with a better lineup of initial customers. Last May, America Online and Gateway declared that Crusoe will power a new line of household appliances that will feature wireless Net access. IBM, Hitachi, NEC and Fujitsu followed suit in June, with announcements of Crusoe-based notebook PCs that will run all day on ordinary batteries. Sony followed with an announcement in August that Crusoe will power a future version of its Vaio PictureBook line of notebook computers. Not bad for a chip company with no fabrication plant and no track record—and whose main asset is, as Ditzel puts it, "a vision of a better way to build microprocessors."

"Starting now, the Transmeta approach will be the smartest, quickest, cheapest, most reliable, most flexible technology to solve virtually any computing-related problem," says John Wharton, microprocessor design consultant, Stanford professor, and former design engineer for Intel. "Fifty years ago, the most sophisticated systems were built using vacuum tubes. Ten years ago, the state of the art was complex, fully integrated megaprocessors like the Pentium and PowerPC. I see Transmeta as representing the next breakthrough in fundamental design technology."

The trail that Transmeta is blazing will lead to chips that use significantly less electric power. That's good news for anyone who uses a laptop computer or other portable electronic devices. But more profoundly, Transmeta has found a way to radically improve the ability of chip designers to make changes in their products without alienating the huge libraries of software that have been written to run on a particular piece of hardware. They have, in a sense, removed the pesky governor from the engine of chip-making progress.

Architecture of Liberation

Although there's been plenty of press coverage of Transmeta as a new venture, what often gets lost is the technology itself. Crusoe is a hybrid software/hardware chip whose sole purpose is to run software designed for other microprocessors. Much of what Intel and others accomplish in silicon, Transmeta has shifted to software. The advantages? First, the chips themselves take less silicon, making them cheaper to build. Second, a simpler chip consumes less power—a paramount concern for portable computers. But perhaps the most far-reaching impact is that in crafting Crusoe, Transmeta has come up with an innovative approach free of many of the problems that have plagued chip design for the last two decades.

Before Crusoe, every microprocessor ever built has come with its own published "instruction set"—an explicit contract that spells out how the chip will work with software. An instruction set promises that if developers write software that does X, the resulting action from the chip will be Y—now and forevermore.

The problem is that once a new chip is designed, it is locked in time. As software inventory for the chip builds, it becomes next to impossible to make improvements to the instruction set. Software development is hampered too, since any new program must obey the laws of the chip's instruction set in order to work. Microprocessor designers want chips to run faster, but they must also make them run on existing software. So they squeak out increments of speed with tricks such as resequencing instructions to the processor. But implementing major changes is next to impossible. It's like a very bad three-legged race, with software and hardware engineers tied at the hip—never able to move fast toward adopting state-of-the-art products, so dependent are they on each other's design choices and the choices of previous generations.

Ditzel himself has firsthand experience with the difficulty of making fundamental improvement in a chip's initial design. At Sun Microsystems, where he worked before founding Transmeta in 1995, he was in charge of changing the instruction set for the company's SPARC brand of microprocessor. Although he embarked on the project in 1990, it wasn't until last year that the new instruction set was ready for use. "You need time for the industry to catch up, to get software out there, to get applications converted," Ditzel told *TR* before the company's IPO. "It's a really big deal."

Morphing Code

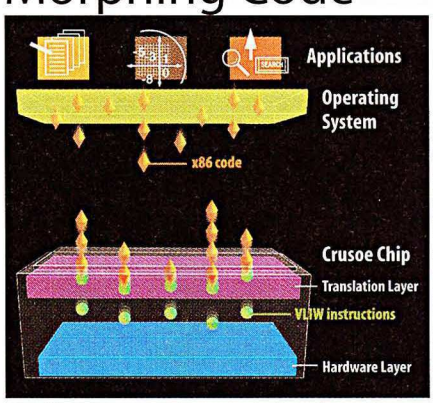


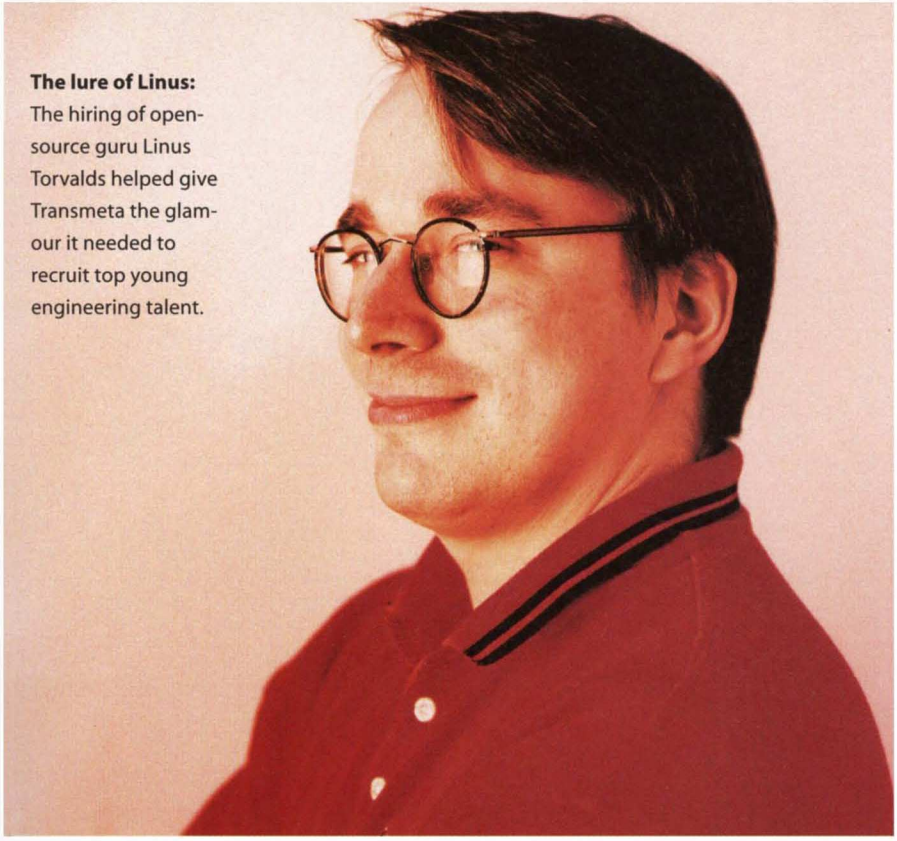
ILLUSTRATION: BESTY HAYES; SOURCE: TRANSMETA

Applications produce code in a form intended for Intel's "x86" processors. Crusoe translates it into a faster-executing form called very long instruction word (VLIW).

Software Camouflage

To wrest their chips from outdated instructions, microprocessor designers will periodically throw everything out and start over with an entirely new chip, complete with a brand new instruction set. It's a process that Intel is struggling through with its much-delayed Itanium microprocessor, which will be the company's first chip that routes data around in digital swaths of 64 bits—that is, on a 64-bit-wide "bus." Freeing designers from the current generation's 32-bit bus will result in a great leap forward in performance. But starting over also results in a chip that will initially have no software to run on it, hardly an ideal state. Even if software developers cooperate and begin to write code to the new instruction set, this approach only works once: Then you're back where you started, with legacy software and a years-long cycle to make any fundamental change.

Ditzel has tried the start-over approach to chip design more than once in his career. Two decades ago, as a graduate student at the University of California at Berkeley, he co-authored a paper entitled "The Case for Reduced Instruction Set Computing." This seminal work



The lure of Linus: The hiring of open-source guru Linus Torvalds helped give Transmeta the glamour it needed to recruit top young engineering talent.

inspired an entire school of microprocessor design; today, so-called RISC chips are everywhere.

After graduate work on RISC design at Berkeley, he moved on to design a RISC-chip variation called CRISP at Bell Labs; CRISP, however, never gained wide support from software developers. Ditzel then made a third attempt to design a new microprocessor when he worked on a gallium arsenide chip at Sun that was never produced. "It was like I was telling people: 'Look! You can use this great new microprocessor—all you have to do is throw out all your software and start over!'" Ditzel said. "I've fought that fight for 20 years, and I've given up."

But he didn't really give up. Instead, he found a way out.

While at Sun in the early '90s, Ditzel was influenced by the work of Russian supercomputer expert Boris Babayan, with whom he had informally collaborated, and whom he names as a key mentor in his developing thought about chip design. At the time, Babayan and his company Elbrus were experimenting with a technique known as dynamic binary translation and compilation (which Transmeta has given the much more market-friendly name "code-morphing," a term they have since trademarked).

Writing code so that one kind of software can run on another kind of hardware is an old idea: IBM, for example, did it back in the 1960s. Results of these attempts, however, were always hopelessly sluggish. But chips were getting faster all the time. By the early 1990s, designers were postulating that there might be a way to translate from one instruction set to another so rapidly that performance would barely suffer. Instead of being a static, one-to-one translation of each instruction, the technique could be dynamic, examining the application for inefficiencies in real time, correcting them and remembering the corrections.

CRUSOE is far simpler than a comparable Pentium, requiring only one-fourth as many transistors.

It is counterintuitive to think that putting an additional layer of software between an application and a CPU wouldn't slow things down—it's like saying a curved line between two points is shorter than a straight line. But the relationship between software and hardware is no longer a straight line: Because of the inefficiencies caused by years of developing around the same instruction set, dynamic translation could, in theory, improve performance. On the hardware side, the process of jamming more and more circuits onto a chip to eke out the last performance gains can actually backfire, slowing things down. Software, too, is rarely as efficient as it could be out-of-the-box: Applications developers with an eye on a ship date will freeze code when it works, not when it's perfect. Dynamic translation could theoretically find the slack and tighten it.

Before Ditzel founded Transmeta, translation techniques had been used only to make existing, noncompatible software and hardware speak to one another. Ditzel and his co-founders made an intellectual leap: If an additional layer of software could make applications run on noncompatible hardware, what was to stop them from making radical changes in the underlying hardware itself, taking advantage of the latest capabilities?

In 1994, Ditzel and co-founder Doug Laird were both coming off a project at Sun designed to make Windows run better on Sun workstations, using dynamic binary translation techniques. "We realized that if we could just add some features to the hardware, we could actually make this thing go pretty fast," says Laird. "It was a cool idea," he adds, recalling that Sun wasn't interested in changing its processor design to make it better at running applications that had been written to run on standard Intel chips. Ditzel and Laird struck out on their own. Ditzel recruited Colin Hunter, a respected expert in emulation techniques, and Robert Cmelik, who had been doing work in code optimization at Sun.

As is often the case in technology innovation, practice proved harder than theory: Transmeta's first chip design ran so slowly that it took the chip half an hour just to boot the operating system. But with each of four chip revisions, the team learned more about binary translation. Five years of painstaking work—performed by a brigade of 200 engineers backed by several hundred million dollars of venture capital—produced a chip that ran fast enough to compare favorably

Thanks, old economy.

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with Intel processors. In January of this year, Transmeta announced the first two hybrid silicon/software chips in the Crusoe line. The first, called TM5400, is a 700-megahertz chip for the ultrathin, ultralight Windows notebook PCs. It runs software written for Intel chips on a fraction of the power a Pentium consumes. The second, the TM3120, is a 400-MHz chip designed to run Internet appliances using a version of Linux that Torvalds developed for mobile devices.

Both chips present a face to software developers that is completely compatible with the instruction set in Intel's processors. Underneath are VLIW chips, for "very long instruction word," an architecture with a 128-bit-wide bus that can combine Intel chip instructions into longer strings and thus execute them faster. Between the outward-facing instruction set and the underlying hardware is Transmeta's code-morphing software, which translates the Intel-style instructions into a form that Crusoe can handle, optimizes their execution and stores the optimized executions in memory. The next time the chip encounters the same operation, translation is no longer necessary. The code-morphing software (which resides in a read-only memory chip) is the first program to launch when the processor boots.

Because so much of Crusoe's functionality has been moved from hardware to software, the chip is far simpler than a

Transmeta's Competition

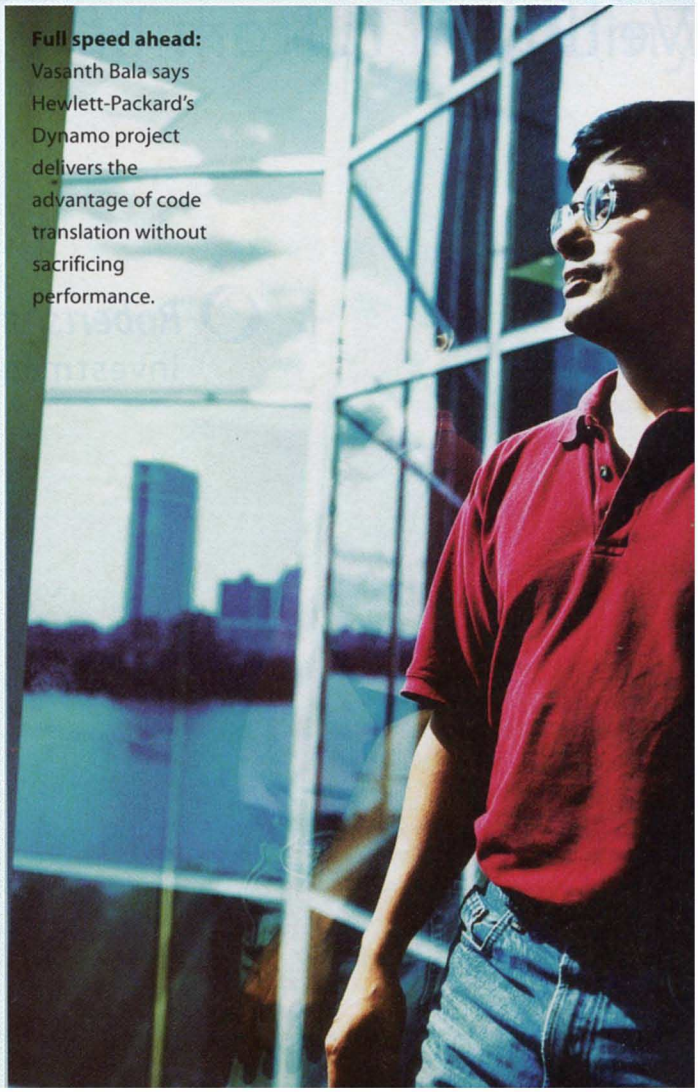
The idea of a product that enables software written for one kind of hardware to run on another kind is not unique to Transmeta. Related products already on the market—albeit with far more modest goals—include FWB Software's SoftWindows for the Macintosh and Unix, Connectix' Virtual PC for the Macintosh, and Sun Microsystems' HotSpot, a relatively simple, Java-based compiler that optimizes code in real time and allows a processor to run Java programs more efficiently.

Other projects are more ambitious. While Transmeta founder Dave Ditzel stopped direct collaboration with Boris Babayan in 1994, the Russian expert has been busy developing chips along similar lines at Elbrus, a Moscow-based group of computer companies; he released a design prototype for his chip, the E2K, in 1999. Babayan claims that the E2K will run faster than Intel's new Itanium chip and still be compatible with all existing Intel-compatible software. Elbrus developed the design with only $2 million of funding; Babayan is confident that Transmeta's success provides the "proof of concept" test that he needs to find additional backers and bring the chip into production. "Transmeta decided to use an approach very similar to the one we used," says Babayan. "Nobody believed this approach would work before. Transmeta has proven that these ideas are good."

At Hewlett-Packard Labs in Cambridge, Mass., researcher Vasanth Bala is heading up a project code-named Dynamo, being tested at four universities. Transmeta's code-morphing technique puts a modest drag on performance; co-founder Doug Laird estimates that the 700-megahertz Crusoe will run only about as fast as a 500-MHz Pentium. Bala claims that applications will run faster with Dynamo than without it. Unlike Transmeta, HP has opted for a software-only approach that focuses on improving performance, even in situations where software is using a microprocessor's native instruction set. "Translation is a very straightforward process," says Bala. "It's the quality of the code optimization software that really makes a difference. We're not asking the chip itself to handle two instruction sets, the way Transmeta does."

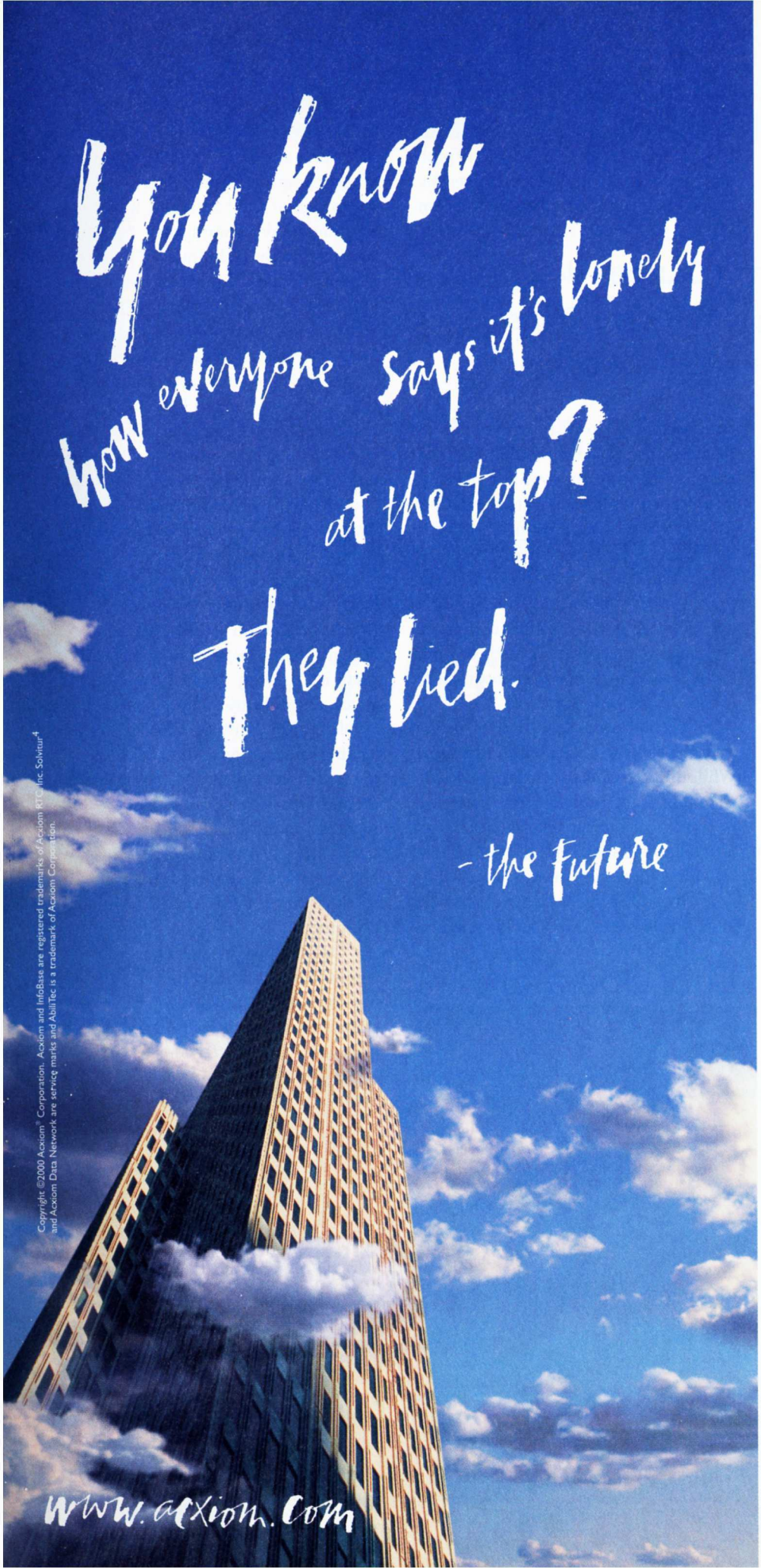
There are many more examples. A six-year-old IBM project code-named Daisy has looked at similar development techniques for the PowerPC chip. Compaq's Wiggins/Redstone project uses a sampling technique to determine where most of the time in a program is spent, then dynamically optimizes program execution. And Intel itself has employed dynamic translation techniques to mimic the Itanium instruction set. Intel research papers on the project give a nod to Transmeta co-founder Robert Cmelik. The goal of the Intel project is to create a virtual Itanium-compatible chip in the software layer, which can run on Intel's current (and ubiquitous) generation of processors. Software developers will thus be able to write applications for Itanium even before the chip is available.

Intel has no public plans to start engineering its next-generation chips Crusoe-style. But it is perhaps the only company with enough marketing clout to muscle in a change as large as the shift to Itanium. In a few years, it may have no choice but to consider the Transmeta approach. In the meantime, Transmeta-like techniques are lessening the pain for software developers by giving them longer lead times to write and test their products.



Full speed ahead: Vasanth Bala says Hewlett-Packard's Dynamo project delivers the advantage of code translation without sacrificing performance.

PHOTOGRAPH BY FURNALD/GRAY



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comparable Pentium processor and requires only one-fourth as many transistors. A side benefit of fewer transistors is that Crusoe uses far less power to run—hence Transmeta's decision to target its first chips at the mobile market. Another advantage to the Crusoe approach is in shortening the time needed to develop a new chip. With much of the design residing in software, Ditzel says some customers have already asked for changes in the instruction set and that Transmeta engineers could implement them in 24 hours. While this probably doesn't include time for any kind of bug testing, it's nevertheless clear that Transmeta has found a way to drastically shorten the development cycle.

WITH so much of Crusoe's design residing in software, Transmeta is able to implement changes in 24 hours.

Nick Tredennick, co-architect of the original Motorola 68000 (the processor that powered the first Macintoshes), and now an independent microprocessor design consultant, is not alone in concluding Ditzel is on to something. "When I first heard about Crusoe, I thought it was just the latest fad, or a rehash of emulation, which has never worked," Tredennick says. But after hearing Ditzel speak, Tredennick became a convert. Transmeta, he says, is doing something "fundamentally different from what has been done since the invention of the computer."

Transmeta's chips are "inherently simpler to design" than conventional ones, says Stanford's Wharton. "You can make a software change, incorporate it into a test version, run it and see if it works, all in one afternoon. In the hardware realm, the turnaround time can be three to nine months. Intel may put 500 or 1,000 man-years into designing Itanium. The next Transmeta chip may require 10, or 20, or 50. That's mouse nuts."

The movement toward making chips that are hybrids of software and hardware, rather than pure silicon, has caught on broadly. But Transmeta is likely to keep the lead for the foreseeable future. That's because Ditzel was the first person to take these ideas out of the lab, hire 200 employees to work on them, and build a chip that worked. Along the way, he created at least two roadblocks that will slow down his competition.

The first is the company's testing tools. Indeed, Transmeta's jewels are probably not even the chips themselves, but rather the diagnostic software the company was forced to create in the development process. The off-the-shelf tools that exist for checking out conventional chips all assume that there is a static relationship between software, a chip and a given instruction. Transmeta needed to solve the problem of testing a microprocessor that changes dynamically in response to the software it runs. Other companies will need to start from scratch to build their own testing tools, which could easily take a year or longer.

A second obstacle is finding people with the skills to design chips like these. While the concept of a combined software-and-silicon chip is sound, everyone at Transmeta appears taken aback by just how difficult it was to pull off the first time. "If you told me up front it would have taken so long, I probably wouldn't have joined Transmeta," says senior engineer Godfrey D'Souza, an early employee.

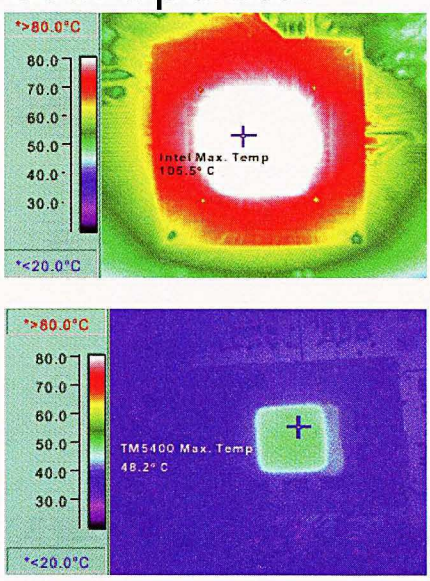
A key factor in Transmeta's success was finding the people with the appropriate cross-training in both hardware and software development, in a world where computer science degrees specialize in one or the other, and where chip designers have always been trained in hardware-only techniques. The lure of stock has allowed Transmeta to raid other companies for people that have the experience—including six engineers from Hewlett-Packard's rival Dynamo project alone. Now they have assembled a team that is the only one to have produced a chip using these techniques. Other companies will be hard-pressed to lure these engineers away. The presence of open-source celebrity Torvalds has also helped Transmeta's recruiting efforts, especially for young engineers.

Transmeta is coy about its plans for a next-generation microprocessor. Speculation abounds on the Internet: Will it be Macintosh-compatible? Run Java? Transmeta isn't saying. In past press conferences, Ditzel himself has acknowledged his delight in planting deliberately misleading information about the company's plans, a strategy he's not above using to throw off his competition. A stray comment last spring about Transmeta's developing a chip for the mobile phone market was widely reported and sent the stock of market leader ARM Holdings plummeting.

One thing is certain: The company's patents baldly state that the technology is not intended for Intel-compatible chips alone. And although Transmeta is going to find it difficult to keep up with current orders, much less conquer new markets, there is no reason to think that the Transmeta way of designing chips won't be widely useful, or that Transmeta won't capitalize on its technology lead.

"We've learned the lessons from the past, and we won't get trapped again," Ditzel told us. "By having this software layer, we can change underlying hardware every year. So 10 years from now, we can have 3,000-bit-wide architecture or whatever the state of the art will be. We can make that change. Everyone is focusing on this first chip. That's not the point. The point is, for the next decade we have a technique that's going to let us move faster than anyone else does. It's a cliché right now, but we can work on Internet time." TR

Cool Operator



During playback of a DVD, a Crusoe chip (bottom) uses less power—and generates less heat—than a Pentium III processor.

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Fill 'er Up With Hydrogen

BY PETER FAIRLEY

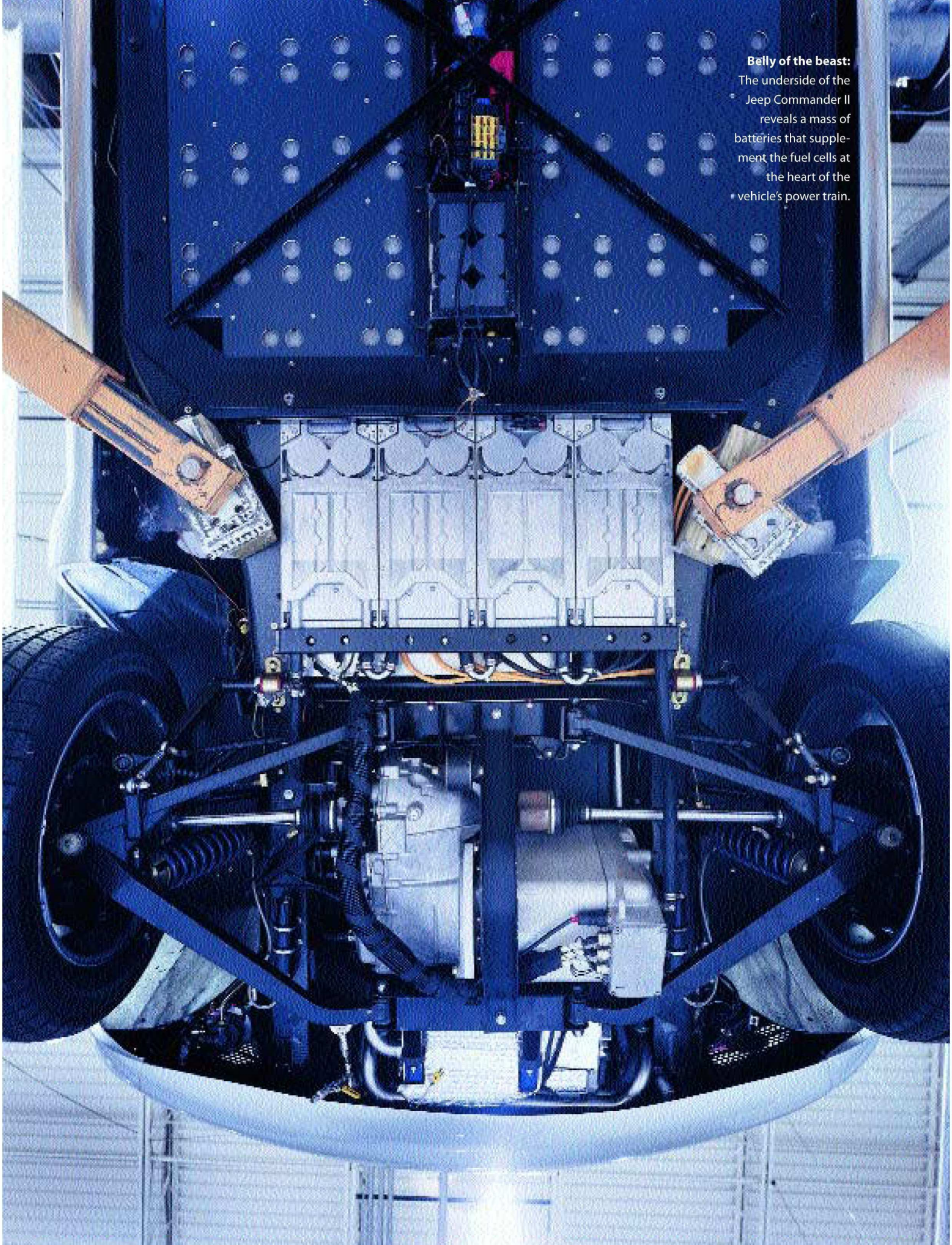
PHOTOGRAPHS BY BERND AUERS

Tired of waiting for an electric car? Automakers have put clean, efficient vehicles powered by fuel cells on the inside track.

WEIGHING IN AT ALMOST 2,600 KILOGRAMS, THE brawny vehicle at DaimlerChrysler's suburban Detroit skunk works seems an unlikely "car of the future." The lines are distinctly late 20th century. Jump into the driver's seat and it feels like your standard sport utility vehicle (SUV). But pop the hood, and it instantly becomes clear that this is no ordinary gas-guzzler: In place of a combustion engine lies a sophisticated onboard refinery—a fuel processor system of high-pressure gas lines, compressors and chemical reactors to turn methanol into hydrogen gas.

This multimillion-dollar moving laboratory—the Jeep Commander II—feeds the hydrogen to two fuel cell stacks, which silently combine hydrogen and oxygen in a chemical reaction that generates enough electricity to hurtle the SUV down the highway. The car's operation is clean and efficient, generating only water, carbon dioxide and some spare heat. Missing are the toxic air pollutants and fine soot that spew from most vehicles' tailpipes.

DaimlerChrysler and its partners—Canadian fuel cell developer Ballard Power Systems and rival automaker Ford Motor Co.—believe that fuel cell vehicles can deliver the power and performance that today's drivers are used to. Commander II shows how tough a challenge this is. While the vehicle represents the state of the art in fuel cell technology, its engine takes half an hour to warm up and would cost several times more to mass-produce than a standard V6. But DaimlerChrysler is closing the gap. Its next fuel cell demo, a hatchback to be unveiled as early as this fall, will pack a fuel cell with twice the punch of Commander II's. Not only will its fuel processor weigh half as much, but it will start up in less than a minute.



Belly of the beast: The underside of the Jeep Commander II reveals a mass of batteries that supplement the fuel cells at the heart of the vehicle's power train.

It is this type of steady and substantial improvements in fuel cell technology that have convinced many automakers and oil companies that the internal combustion engine has finally met its match. Facing tighter regulation of tailpipe emissions, several automakers are investing heavily to lead the transition. DaimlerChrysler, Ford and Ballard have spent close to $1 billion on fuel cells and plan to spend at least a billion more by 2004 to begin mass-producing vehicles. The goal is to take fuel cells out of the skunk works and into the showroom. "The great majority of our people who are working on fuel cells are working on the production program," says Bruce Kopf, director of TH!NK Technologies, Ford's electric car enterprise.

Ford and DaimlerChrysler's competitors have joined the race, along with major parts suppliers (*see "Putting Fuel Cells on the Road," p. 62*). Japan's four largest automobile makers invested more than $850 million on fuel cells over the past decade, and several are committed to commercializing the technology—possibly even before DaimlerChrysler and Ford.

These companies are excited about fuel cells because the internal combustion engine is getting harder to improve. Even the most sophisticated designs will struggle to meet the tougher emissions standards soon to be imposed in California and several states on the East Coast. And cleaning up the internal combustion engine is beginning to increase its cost. After 100 years of improvements, combustion technology is reaching its limits.

Fuel cells are also appealing because they will free electric cars from battery power, which provides the cleanest cars on the road today but also dooms them to a niche market. Battery-powered cars are zippy and responsive, and nearly silent without the rattle and roar of pistons. But these features have been overshadowed by the vehicles' limited range. Batteries simply haven't improved much since they were driven off the road by the internal combustion engine nearly a century ago. "The electric car's inherent limitations essentially doom it to a very small operating range, and that's the story today," says historian Robert Casey, curator for transportation at the Henry Ford Museum in Dearborn, Mich. "The electric car has been the car of the future for the last hundred years."

Membrane Magic

ONE WAY TO EXTEND THE RANGE OF THE electric car is to carry fuel and generate electricity onboard. This is the approach used by hybrid gasoline-electric cars such as the Toyota Prius, which hit U.S. showrooms this summer. The Prius employs a small, efficient combustion engine, plus a pile of batteries that supplement the engine during acceleration and absorb power from the wheels during braking. The problem with this solution is that it is inherently complicated and costly, since it combines electric and mechanical drive technologies. Robert Winters, a power technologies analyst with Bear Stearns in New York, says that the Prius is "heavily subsidized," and wonders whether hybrids will ever be affordable. "You've got a redundant engine system in there. How are you going to overcome that?"

Fuel cells generate electricity on the fly. Carry enough fuel, and your vehicle will go as far as you want.

Enter the fuel cell. Unlike batteries, which store a charge, fuel cells generate electricity on the fly. Carry enough fuel, and the fuel cell will take your electric vehicle wherever you want to go. Winters says fuel cells are rapidly becoming a commodity, and vehicles carrying them could easily account for "several percent" of the 60 million or so cars that will be produced worldwide by 2010.

Though fuel cells come in half a dozen varieties, utilizing different fuels and materials, one version has emerged as the clear favorite for automotive use: the proton exchange membrane (PEM) fuel cell. A PEM cell is solid and compact and operates at a relatively cool 80 C. The heart of the PEM cell is a rubbery plastic membrane coated with a platinum catalyst. The catalyst splits hydrogen gas into protons and electrons; only the protons can pass through the membrane. The electrons travel around the membrane, generating the treasured electric current, before recombining with the protons and oxygen on the other side of the membrane to generate water. Stacking a series of these membrane-catalyst assemblies, or "cells," multiplies the voltage.

PEM stacks lit the Gemini spacecraft that circled Earth in the 1960s, but generated a trickle of electricity too weak and expensive for commercial applications—let alone automobile engines. Then, in the late 1980s, researchers at Los Alamos National Laboratory made major advances in catalysts, reducing by 90 percent the amount of platinum required. Ballard multiplied the stack's power density—the power returned per unit of precious vehicle space it occupies—by learning how to keep the membranes happy (wet but not soaked) and by perfecting the plumbing that moves hydrogen, oxygen and water through the stacks. Ballard, based in Burnaby, B.C., has close to 400 patents issued or pending to protect its lead in PEM technology.

Two years ago Ballard exceeded the minimum power density for automobiles—1,000 watts per liter—with its Mark 700 stack, two of which propel Commander II. Ballard's Mark 900 stacks, released early this year, put out as much as 1,350 watts per liter. "That's a power density that is practical for today's vehicles," says Paul Lancaster, Ballard vice president for finance. In other words, a car packing such a stack should accelerate the family road machine, luggage included, with the same gusto as an internal combustion engine.

Steering Around Obstacles

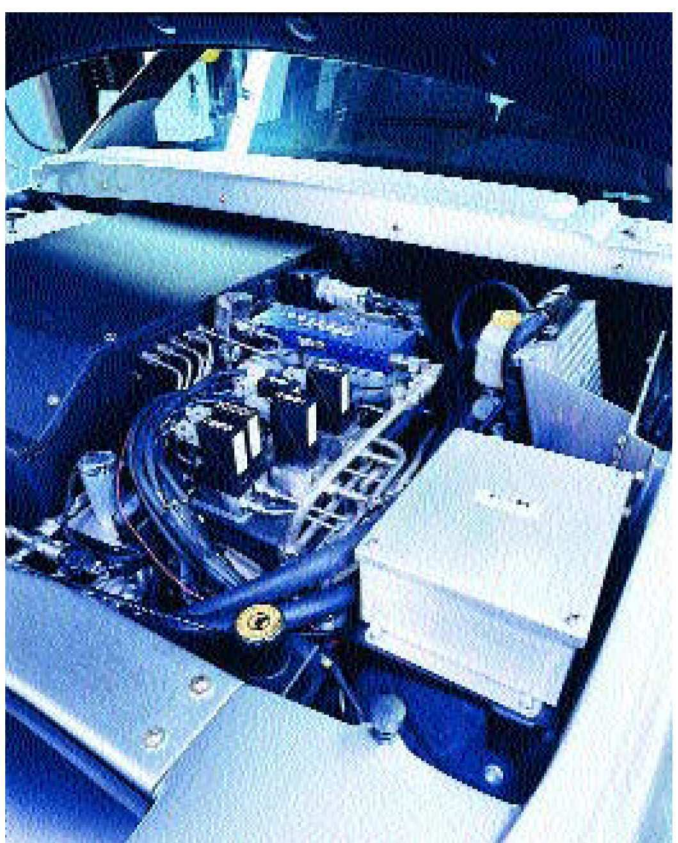
BUT HOLD ON TO YOUR CHECKBOOK, because more work remains to make the fuel cell vehicle practical. All of its systems are too costly—even pricier than loading a car with batteries—and supplying hydrogen to the stacks is still a struggle.

Ballard's top challenge is manufacturing cheaper stacks. The company is working with Ford and DaimlerChrysler to optimize its stack designs for cheap, automated production. And to achieve a critical mass of production, Ballard is commercializing fuel cells in multiple markets simultaneously—not just vehicles but portable power generators, residential generators and stationary power plants. Lancaster pegs the breakeven point at about 300,000 stacks per year. "To the extent possible, we've used common materials and common manufacturing processes across product lines, so we don't have to make fuel cells for 300,000



Under the hood: The fuel processor (dark box) converts methanol into hydrogen; it is served by ancillary electronics and plumbing.





cars to achieve that volume."

DaimlerChrysler and Ford, meanwhile, are focusing on making the rest of the car. Their biggest headache has been keeping the stacks fed with hydrogen. "The issue with fuel cells has become the fuels. It's not the fuel cell anymore," says Mohsen Shabana, who as the fuel cell vehicles program manager at DaimlerChrysler's engineering technologies operation in Rochester Hills, Mich., is responsible for making Commander II run. All three of the fuels that carmakers are considering—gasoline, methanol and hydrogen—pose serious challenges.

Onboard extraction of hydrogen from gasoline would make the transition to the fuel cell vehicle seamless, since gasoline is everywhere. But refining gas on the go is difficult. The reactions occur above 800 C, making the devices slow to start, and the chemistry is temperamental; while the process is routinely used in chemical manufacturing plants and oil refineries to make industrial volumes of hydrogen, squeezing it under the hood is tricky. Another unsolved problem is protecting the fuel cell from the catalyst-poisoning sulfur in gasoline.

Despite the technology challenges, General Motors and Exxon Mobil have recently announced the joint development of a gasoline fuel processor and say a demonstration vehicle using fuel cells powered by the processor could be ready within 18 months. The automaker argues that while hydrogen will likely be the fuel of the future, gasoline processing technology will provide a critical transition in making fuel cell cars practical.

Others are unwilling to wait for the gasoline processor. DaimlerChrysler is developing a methanol system. Some fuel cells run directly on methanol rather than hydrogen, but fuel cell experts say this technology is at least seven years away from the level of efficiency required to power a car. So using methanol as a fuel today means extracting its hydrogen. Methanol is an easier target than gasoline because it is sulfur-free and yields hydrogen at a relatively mild 300 C. But refining methanol is still a complex process involving many steps, each of which must take place at a particular temperature.

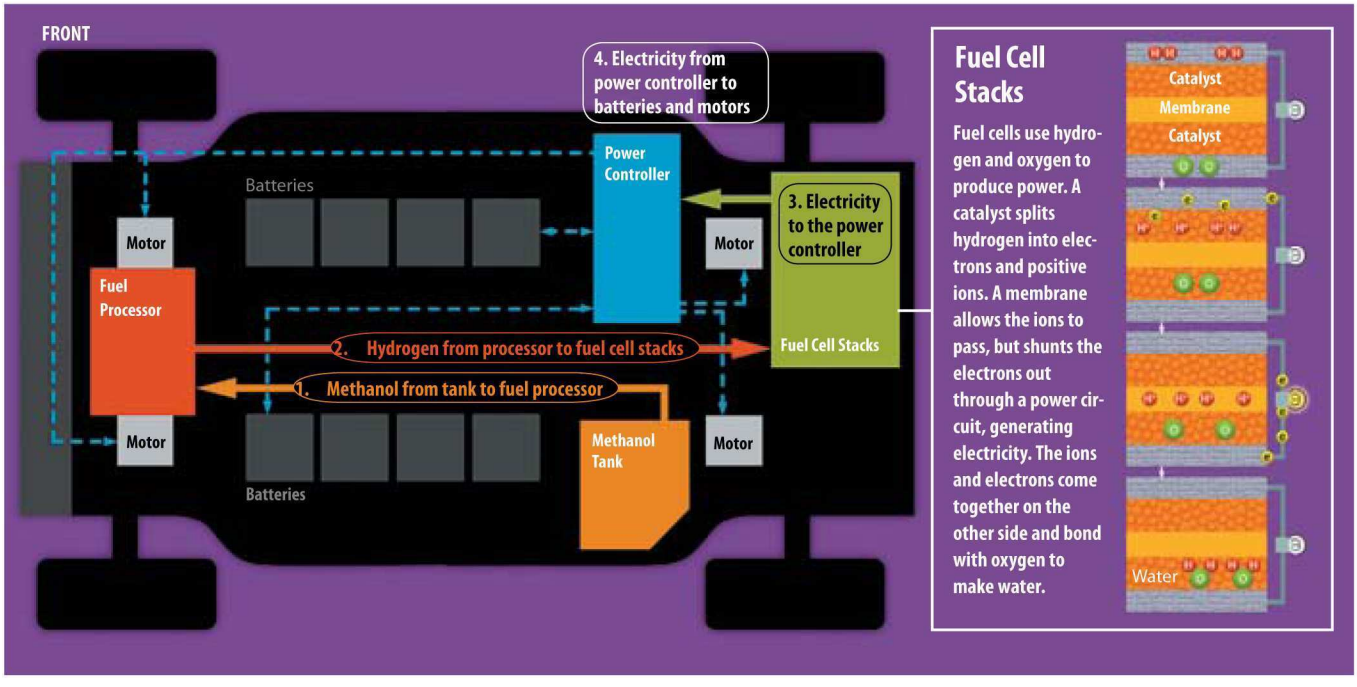
Graphite fibers absorb more than 20 percent hydrogen by weight, allowing more of it to be stuffed into the tank.

The methanol processor under Commander II's hood chugs out enough hydrogen to take the vehicle a shade under 200 kilometers between methanol fillups. The range is limited by the small size of the fuel tank—a consequence of the bulky fuel processor. The big hangup, though, is that the fuel processor takes a half-hour to warm up, which is a half-hour longer than drivers are willing to wait. The problem is that the processor uses steam to free the hydrogen, and getting up a head of steam takes time—just as it did for the steam cars of the early 1900s.

DaimlerChrysler, Ford and Ballard say they are working on a solution: a next-generation fuel processor that uses a catalyst, rather than steam, to kick-start hydrogen production. The new system is much smaller—slightly bigger than a file box—and weighs half as much as the beast squeezed under Commander II's hood. But this sophisticated little fuel processor has been a long time coming. Ford and DaimlerChrysler both planned to show the technology in demo cars this spring, but only Ford's appeared on the auto show circuit—and its fuel processor was not functioning. Ford's Kopf says the two companies decided to pool their resources—including the scarce automotive engineers comfortable with the electric vehicle's communications systems—to get the processor working in DaimlerChrysler's next concept car. "The system is so complicated, and it's got a lot of computers talking to each other," says Kopf. "There are not a lot of people in the world capable of making these run."

While these elite engineers fuss over catalysts and controls, doubts are growing over the viability of methanol as a

Inside a Fuel Cell Car



BETSY HAYES

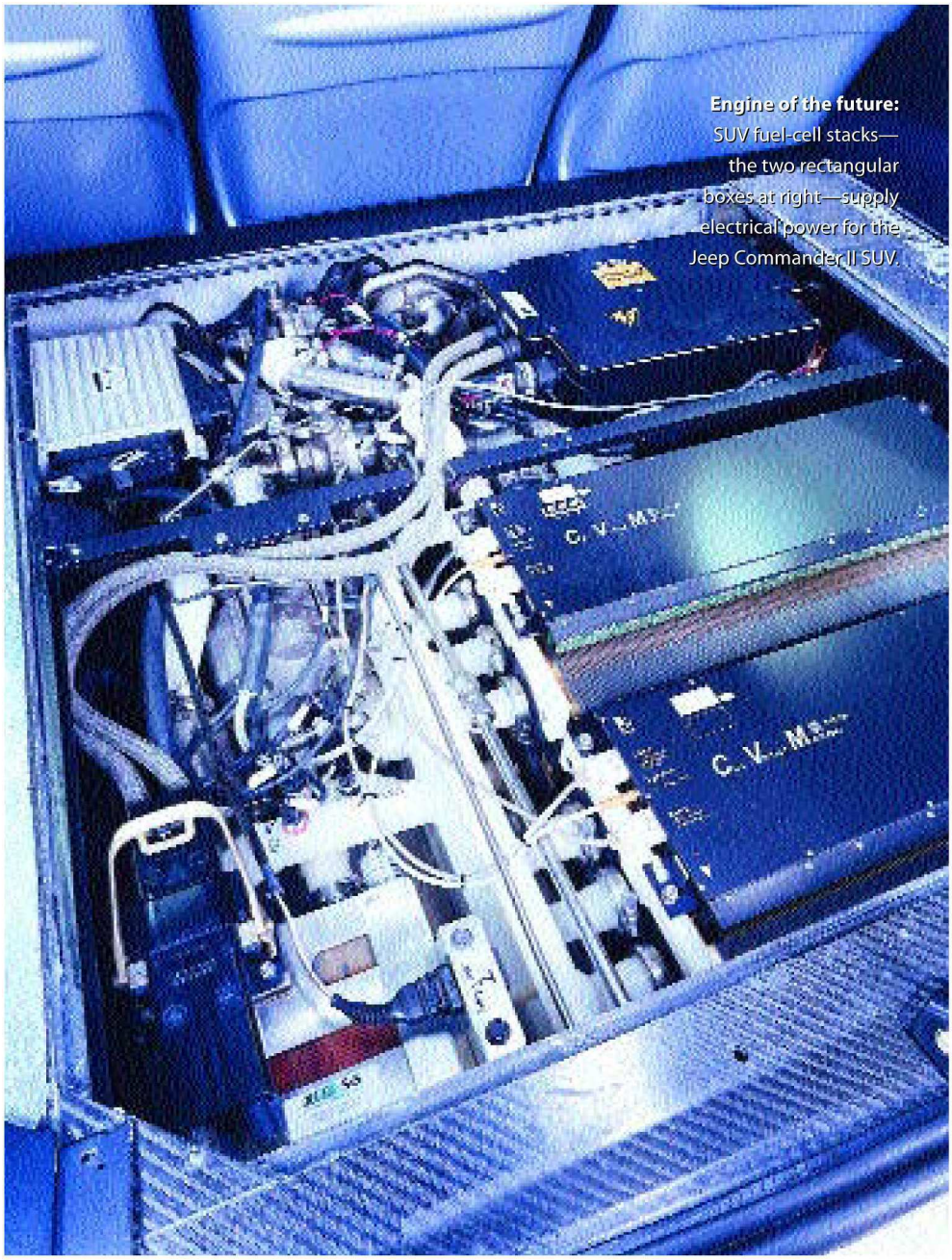
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Engine of the future: SUV fuel-cell stacks—the two rectangular boxes at right—supply electrical power for the Jeep Commander II SUV.

consumer product. Methanol is nasty stuff—not only can it prove fatal if ingested, but even splashing it on the skin can cause blindness and liver and kidney failure. And because methanol dissolves in water, it poses a threat to underground drinking water supplies. That makes oil firms nervous; they are already scrambling to get the methanol-based fuel additive MTBE (methyl tertiary butyl ether) out of their gasoline, after the foul-tasting chemical began showing up in California's drinking water.

The most obvious solution, of course, is to directly use hydrogen as the fuel. That would eliminate the need for a reformer as well as the climate-warming carbon dioxide it generates (though some CO_2 would still be released during hydrogen production from fossil fuels, the most common method today). The problem is that while hydrogen packs more energy by weight than any other fuel (about three times more than gasoline), it is hard to stuff much of this energetic gas in a fuel tank. Pack a commercially available compressed gas tank with hydrogen, and it will take your vehicle barely 150 kilometers—no farther than today's best car batteries. Hydrogen is also the smallest of molecules and slips through the smallest holes—a worrisome trait, given its characteristic flammability. (Remember the Hindenburg?) DaimlerChrysler pushed a demo car 450 kilometers using a liquid hydrogen tank, but the cryogenic technology to store fuel at –253 C (just 20 degrees above absolute zero) is not mature for mass markets. And good luck finding a hydrogen filling station—there are only a half-dozen worldwide.

Hydrogen availability may become less of an issue, though, as major oil companies warm to the challenge of distributing the gas. Graham Batcheler, president of Texaco Energy Systems, the oil giant's advanced-fuels subsidiary in Houston, says the company believes that the fuel cell will replace the internal combustion engine over the long haul. He considers it inevitable that drivers will be filling up with hydrogen—and he wants them to do it at a Texaco station. Rather than fighting to protect its gasoline franchise, Texaco is investing in the key technology to make hydrogen fueling possible: advanced storage tanks.

One possibility for solving the hydrogen packing problem is simply rethinking compression. Stronger tanks could compress the hydrogen to greater pressures, or radically redesigned vehicle frames could accommodate massive but oddly shaped tanks. Another option is to pack tanks full of materials that bind hydrogen, slowing down the molecules without liquefying the gas. Graphite fibers with intricate nanostructures, for example, have been shown to absorb more than 20 percent hydrogen by weight, allowing far more of the gas to be stuffed into a tank.

Consuming Visions

GIVEN THE CHALLENGES, JOHANNES Ebner, the executive in DaimlerChrysler's fuel cell program responsible for fuel infrastructure, acknowledges that earlier company estimates putting 20,000 to 40,000 of the cars on the road in 2004 now look unrealistic: "It will be a very limited production." Ballard, DaimlerChrysler and Ford will begin testing their technologies on consumers next year in California, where tough requirements for pollution-free vehicles are set to take effect in 2003. The California Fuel Cell Program (formed by these three companies along with other carmakers, fuel cell makers and several big oil companies) plans to put 60 fuel cell cars and buses on the road—taking fuel cell vehicles out of the hands of careful engineers and into the hands of demanding consumers.

These California cars, like the Commander II, will be custom-built. The real test for fuel cells will come when mass-produced cars hit the road—which both



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Ford and DaimlerChrysler have vowed to do in 2004 despite knowing that they will lose money on them. "We've stated we'll have vehicles in the public's hands, and there are programs in place to do that, but that doesn't mean they're commercially viable," says Ford's Kopf. He concedes that fuel cell cars are now "a lot more expensive" than battery-powered cars, which themselves are not cheap. Ford would have to charge at least $35,000 to cover costs on its battery-powered Ranger pickup, almost three times more than the price tag that wins it a profit for a no-frills combustion-engine Ranger.

Why are carmakers laying plans to lose money? Kopf says there is always the possibility that the technology will pay off sooner than expected. Instability in the Middle East, for example, could bump gasoline to $5 per gallon, sending Americans searching for fuel efficiency just as the oil crises did in the 1970s. "We want to have developed a core engineering capability—to know where the problems are, where we need to simplify. We want to be prepared."

But he says the ultimate motivation is long-range. The fuel cell promises to make the automobile sustainable, cutting pollution and freeing it from the politics of oil—and ensuring that Ford can make as much of a killing in this century as it did in the last. The big appeal of fuel cells is "the promise of zero tailpipe emissions, potentially no greenhouse gas emissions and energy independence," says Kopf. "Those are the holy grails of the automotive industry."



In the driver's seat: Consumers may be able to take the wheel of fuel cell vehicles like Jeep's Commander II by 2004.

Looking into the future, Kopf imagines a world in which electricity from renewable sources such as wind and solar cells generates hydrogen from water—the reverse of the fuel cell process—to power a fleet of fuel cell vehicles. "You could make a fuel system and vehicle that produces zero greenhouse gases and zero tailpipe emissions—a hydrogen-oxygen-water cycle that is sustainable forever. That's the ultimate goal."

One might expect that kind of talk to unnerve the leaders at DaimlerChrysler, who recently announced a crash program to cut $2 billion from operations to quell shareholder anxiety over declining share prices and weak returns. But Ebner says DaimlerChrysler chairman Juergen Schrempp is personally protecting the fuel cell program's $1 billion line of credit as a "pipeline to the future." Schrempp's vision sounds even more messianic than Kopf's.

In a recent speech to the World Engineers Convention, the engineer-turned-business leader implored engineers "around the world" to throw down their projects and jump on the fuel cell bandwagon. Schrempp's rationale? Ensuring that future generations are not overwhelmed by global climate change and economic dislocations from declining oil supplies. "We all share the responsibility for carrying out this project, for the assumption of responsibility is part of the dignity of human beings." ◊

Putting Fuel Cells on the Road

COMPANIES	STRATEGY	PLANS
DaimlerChrysler, Ballard Power Systems, and Ford Motor	Partnering to commercialize fuel cells, fuel processors and electric drives. Ballard is focusing on cutting the costs of fuel cells, while DaimlerChrysler and Ford are demonstrating integrated vehicles running on compressed hydrogen, liquid hydrogen and methanol.	Scheduled to demonstrate 30-40 vehicles in California between 2001 and 2003. Designing models for "limited production" in 2004.
GM and Toyota	Partnering on electric cars. Both companies, leaders in battery and gasoline-electric hybrid technologies, have developed fully functional fuel cell concept cars, fuel cells and hydrogen storage systems.	Expect to have fuel cell cars ready for commercialization by 2004. Ongoing investment in gasoline fuel processors.
Honda	Bullish about its ultra-clean internal combustion technology, but also investing in fuel cells. Honda has built fuel cell concept cars with Ballard stacks and proprietary stacks, but equipment occupies rear passenger space.	Plans to have a package of technologies ready for commercializing fuel cell cars by 2003, but hasn't announced production plans yet.
Nissan	Adapted its battery-powered station wagon to carry Ballard fuel cells and a methanol processor, but equipment occupies rear passenger space.	Next prototype to stow equipment under the floor. Could produce fuel cell cars as early as 2003.
BMW, International Fuel Cells, and Delphi Automotive Systems	Partnering to replace batteries with fuel cell auxiliary power units (APUs) in combustion-powered cars.	Plans to commercialize fuel cell APUs by 2005.



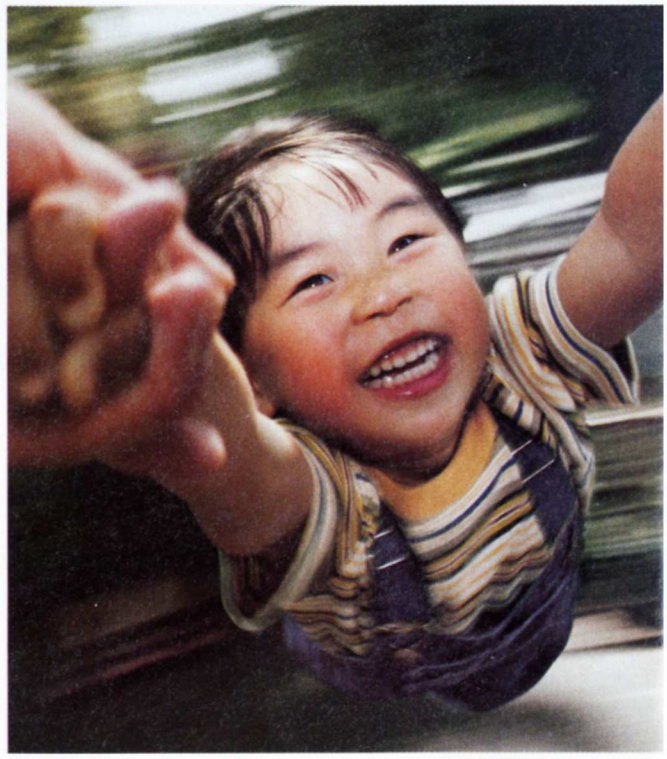
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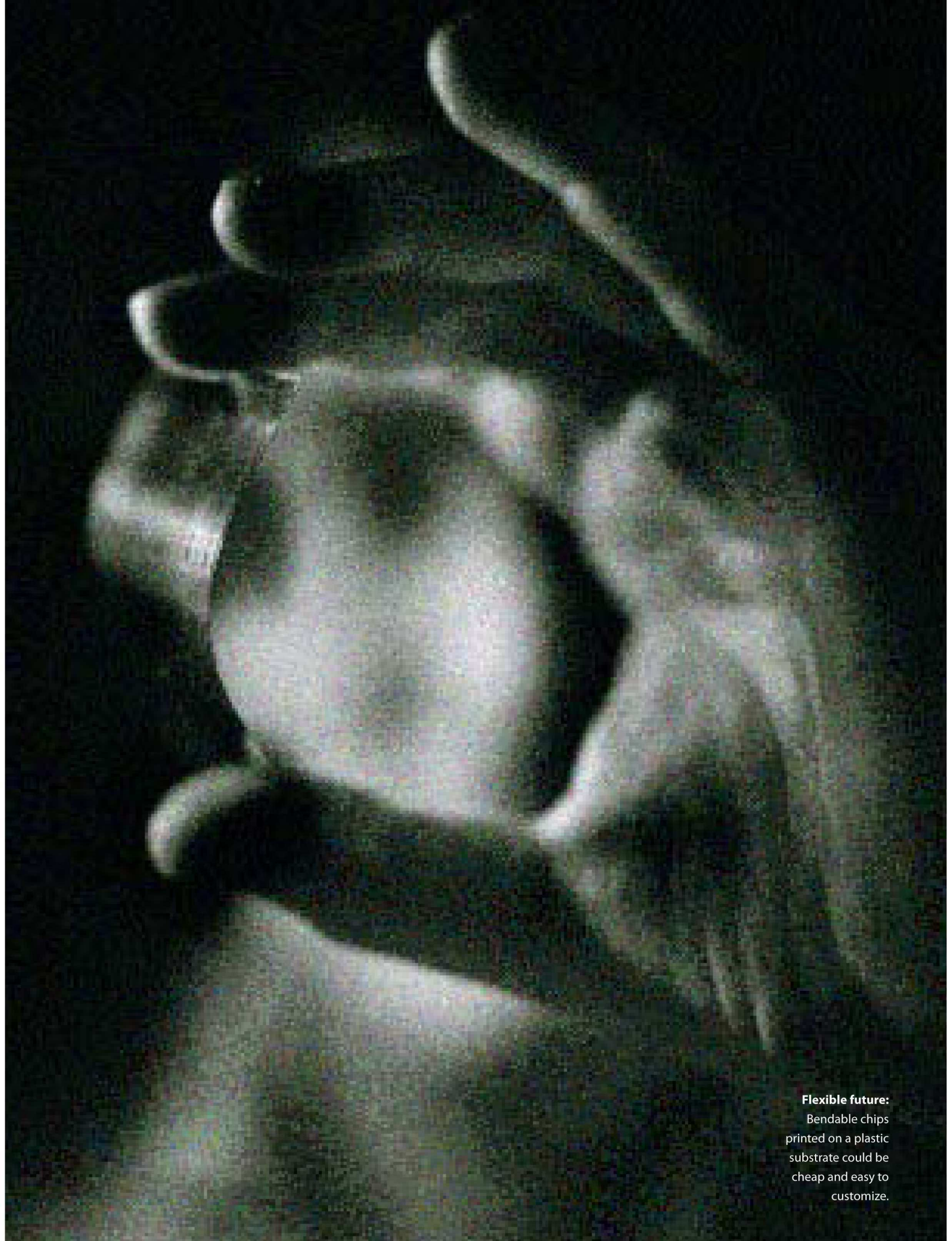
FORGET BILLION-DOLLAR CHIP FABS. IF MIT'S JOE JACOBSON HAS HIS WAY, YOU MAY BE PRINTING CHEAP SEMICONDUCTOR CHIPS ON YOUR DESKTOP.

BY STEPHEN MIHM

AS JOSEPH JACOBSON IS FOND OF POINTING OUT, FOR ALL THE GAINS IN SEMICONDUCtor chip performance over the past few decades, a typical integrated circuit—the brains behind your computer—is still far too expensive for most people on the planet. "Look at the way [a chip] is made," he says, punching the air with one hand while directing a PowerPoint presentation with the other. Fabricating a high-quality logic chip like Intel's Pentium processor, he points out, takes "two weeks, seven days a week, 24 hours a day. Chip fabrication facilities like the ones that Intel has are a $1.6 billion tool. And there are very few people on the globe who can touch that tool."

Jacobson's solution: a "desktop fab" able to print circuits directly on a substrate, such as plastic, without the expense and hassle of a multibillion-dollar manufacturing facility. Jacobson, head of the Printed PC Group at MIT's Media Lab, has already managed to print rudimentary but working transistors using an "ink" consisting of nanometer-sized semiconductor particles. "Our goal is to follow the trajectory silicon took, and start printing processors with perhaps several hundred transistors, moving to thousands and then more," says Jacobson. "We should be able to demonstrate a very simple processor in the next 12 to 18 months." And he predicts that printed logic chips with the speed and power of a Pentium could eventually be possible, making microchips available for a fraction of the time and expense associated with conventional manufacturing.

PHOTOGRAPHS BY KATHLEEN DOOHER



Flexible future: Bendable chips printed on a plastic substrate could be cheap and easy to customize.

If Jacobson's vision becomes reality, it could change everything in computer hardware. Printed electronics could be cheap enough to find their way into everything from "wallpaper" able to display changeable images to custom-designed logic circuitry. A chip fab on every desktop could bring about the day when individuals download the architecture of integrated circuits the way they download software today. It could, in short, transform hardware manufacturing much the way the "open-source" movement has changed how software is written. Indeed, at his most visionary, Jacobson contends printed logic could give rise to an open-source hardware movement where chips are custom-designed via the Internet and printed by the consumer in about the same time it takes to print out a Web page. You could, says Jacobson, "download the chip design from the Web, tie in some modifications from some guy in India, and boom—out comes the device."

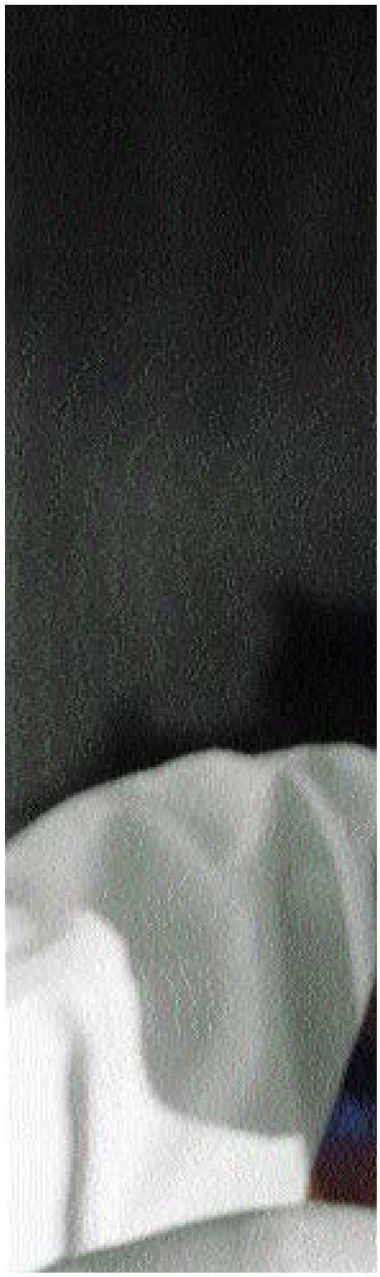
It's lunchtime in Jacobson's lab, a windowless room with tangles of colored cable dangling from the walls and ceiling and a row of chemical hoods set along one wall. Jacobson's enthusiasm is contagious, and the cramped lab is obviously where he and his handful of students spend most of their time, even when they're eating. "What we're interested in is 'give me a piece of plastic and in a few seconds I'll give you back a Pentium,' or something of that complexity," he says between mouthfuls. "I'm serious about that. Not slower than a Pentium; indistinguishable from a Pentium."

Coming from almost anyone else, such a claim would be hard to swallow. But the 35-year-old associate professor has the credentials to deliver the goods. After all, when Jacobson joined the Media Lab in 1996, his immediate ambition sounded nearly as outlandish. "I wanted to have a display [screen] that could be printed," Jacobson recalls. "I wanted something that was incredibly inexpensive, something that would look like ink on paper." Something, in other words, like "electronic paper."

His solution was a riff on research conducted at Xerox Palo Alto Research Center (PARC) in the 1970s, where researchers had created microscopic balls that were black on top, white on the bottom. An electric charge determined which side of the balls rotated upward. With some clever wiring, the balls could be made to form letters and words. Jacobson and a handful of MIT undergrads pushed the idea in new directions. Rather than making balls of two colors, they fabricated millions of tiny microcapsules, each containing a liquid mixture of oil, dark dye and tiny shards of white pigment. They then layered the material onto flexible plastic and sandwiched it between transparent electrodes on top and bottom. Depending on the charge applied, the white shards migrate toward the top or bottom of the sphere, and when activated in concert, the electrodes can force the ink into recognizable patterns.

The rest is the stuff of venture-startup legends. E Ink was formed in 1997 with several of Jacobson's students at the helm, and has since raised nearly $55 million in private financing, forming deals with the likes of Motorola and Hearst Publishing. Media and pundits alike have proclaimed the technology as the end of paper as we know it. But what got lost in all the buzz over electronic paper is that you still need electronics to drive the pixels (the ink) of the displays. The prototypes built thus far by E Ink continue to rely on traditional (read: not cheap) silicon chips to control the display. To reap the full benefits of the technology, you need cheap, flexible electronic circuitry. E Ink has recently partnered with Lucent Technologies, whose researchers have been working on ways to print organic transistors onto flexible plastic substrates. (The two companies hope to unveil a working prototype of the technology this fall.)

Jacobson, however, has even larger ambitions. Not only does he want to print the relatively simple electronic circuitry required to control a display screen, he wants to go the next step and find a way to fabricate high-quality logic on the order of a Pentium using similar printing methods. Not only would you be able to "print" your screen; you could, in a sense, print the PC itself—or at least its essential circuitry.

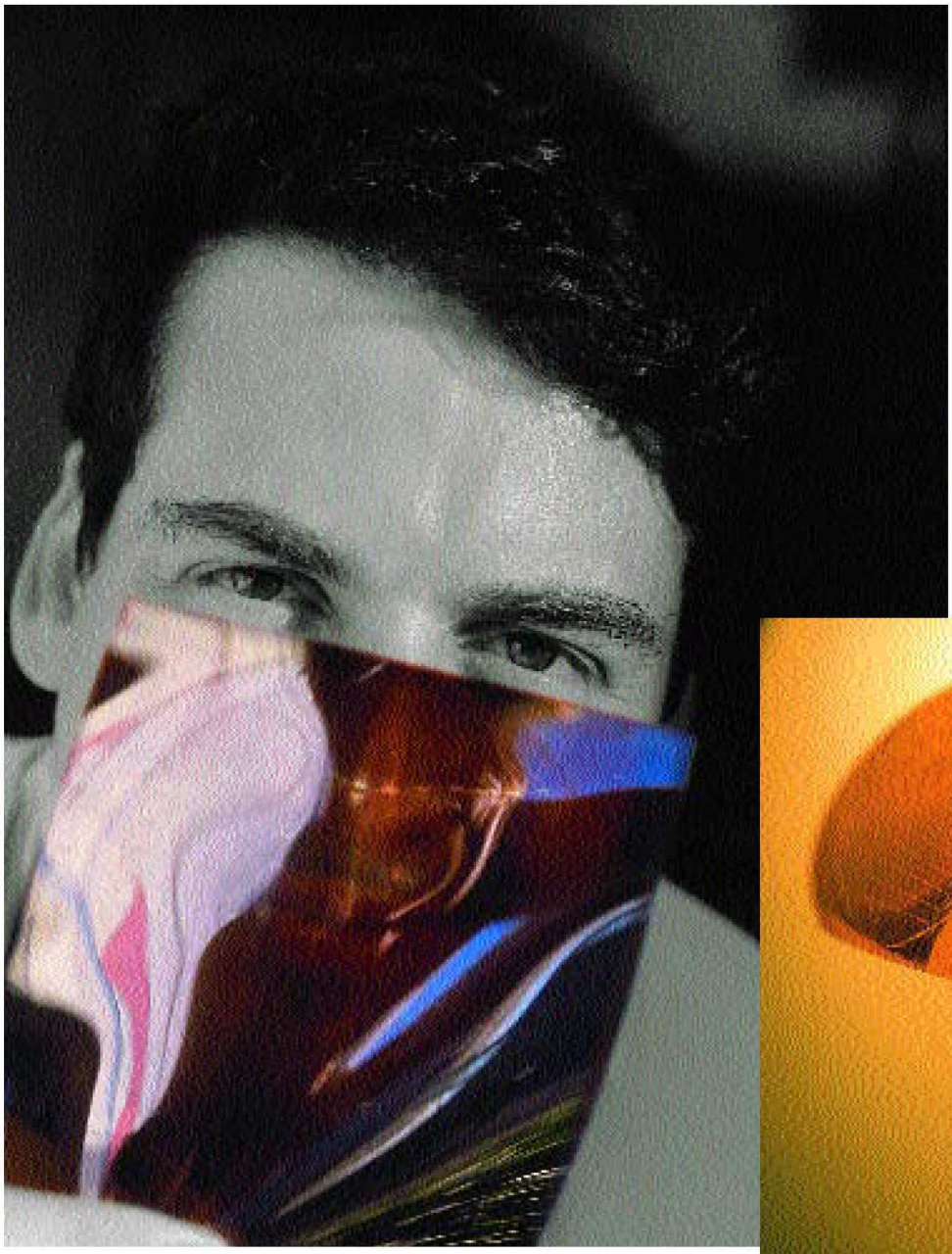


Inorganic Solution

MAKING A CHIP AS POWERFUL AS A Pentium by traditional means is not an easy feat. While semiconductor makers like Intel have learned to make transistors smaller and smaller over the past few decades, squeezing vastly more performance into the microprocessors, the basic mechanics of chip making haven't changed much. The base material remains silicon, sliced into thin wafers. An insulating layer of silicon dioxide goes on top of the wafer; a thin layer of "photoresist" (a light-sensitive material) is deposited on the silicon dioxide. Light beams project the pattern of the circuit onto the photoresist through a stencil; the pattern is then etched out by acids or reactive gases. Additional layers of silicon are added, "dopants" such as boron or arsenic are put into the mix, and finally the transistors are linked by means of tiny aluminum wires.

A fab on your desktop could give rise to an open-source hardware movement where logic chips are designed via the Internet and then printed out like paper.

The resulting microchips are a marvel of engineering and are largely responsible for fueling the Information Revolution. Using multibillion-dollar manufacturing plants, Intel and others can now make transistors as small as a few hundred nanometers across (a nanometer is a billionth of a meter), packing tens of millions of them on a single chip. The downside is that the several hundred manufacturing steps take upward of two weeks



Printed prototypes: Jacobson holds circuitry made by stamping (left and far bottom) and using an inkjet printer (below).



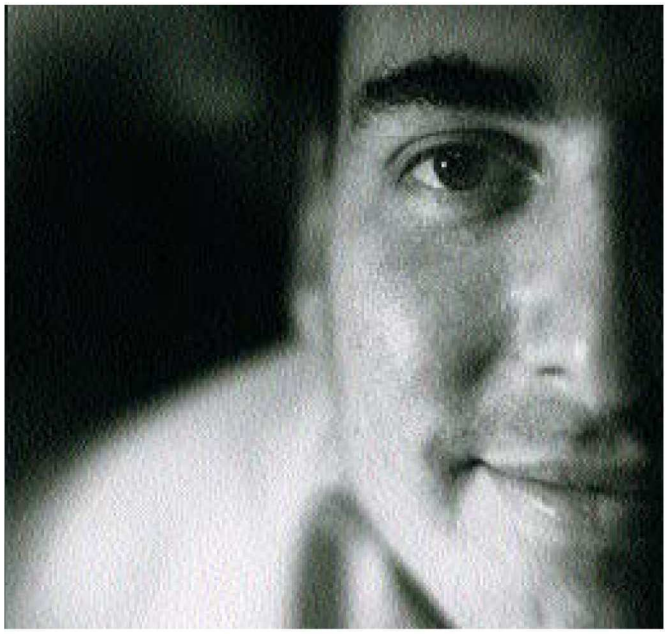


and require clean rooms hundreds or thousands of times more pristine than your average laboratory.

Last fall, Jacobson and his student Brent Ridley described in the journal *Science* the first printed inorganic transistors. Several other research groups, most notably at Lucent's Bell Labs and Cambridge University in Britain, have also printed transistors. These groups, however, are using organic polymers; such materials could have great promise in the electronics required to make cheap, flexible displays. But organic transistors appear to be inherently limited in computing speed. Jacobson's big breakthrough is that he and his colleagues at the Media Lab have created liquid suspensions of inorganic semiconductors—the same class of materials used in your Pentium chip—so that they can be used in a printing process. In other words, rather than carving logic into a solid piece of silicon, Jacobson is simply printing it onto a substrate.

Jacobson's optimism is justified by his group's rapid advances in synthesizing "semiconductor ink." Under normal conditions, semiconducting materials such as silicon, cadmium selenide and gallium arsenide form bulk crystals with melting points well over 1000 C. Jacobson and his team, however, have found a way to synthesize a solution of tiny "nanocrystals" of 100 atoms or less. This semiconductor ink can be patterned or printed onto a variety of substrates, including thin sheets of plastic, at temperatures under 300 C. The particles, Jacobson notes, are small enough to form 200-nanometer structures—about the scale of complex integrated circuits like Intel's Pentium chip.

The suspension of nanoparticles is so similar to conventional inks that Jacobson and his co-workers are able to use an inkjet printer manufactured by Hitachi to fabricate tiny machines called MEMS, or microelectromechanical systems. MEMS, which are one of the fastest-growing new areas in materials technology *(see "May the Micro Force Be With You,"* TR *September/October 1999),* are typically made using many of the same arduous techniques used to fabricate conventional silicon microchips. Using the inkjet printer, Jacobson and his students have managed to fashion both a working thermal actuator and a



Jacobson's vision: Printed logic could change the meaning of "hardware."

linear-drive motor with features on the order of 100 micrometers by simply depositing hundreds of layers of ink. And they are able to form the tiny machines without a clean room and at temperatures well under 300 C.

The group has also used the inkjet printer to produce much more intelligent radio-frequency identification tags. Others are also working on such tags but are relying on logic using organic transistors. Jacobson thinks that the faster logic possible with inorganics can make his version of the tags far more intelligent, allowing companies to track everything from expensive goods to the packages in a supermarket. A radio signal detector could read the devices, update them and integrate them into inventory systems. A person could walk into a supermarket, pick up some items and walk out, and the money would be automatically tallied up and deducted from his or her bank account—and from the supermarket's inventory system.

Using printed circuitry like that is just the beginning. Because the computer logic is printed, it can be put on the surface of almost anything: soup can labels, textiles, soda cans. "You could add intelligence to almost anything you want," claims Colin Bulthaup, one of Jacobson's students. "One thing we want to do is build a digital camera in a business card: everything embedded into the card itself. There's no reason to have all these clunky silicon chips. You can pattern your semiconductor, your photodetector—all the materials together—and integrate them into a single device, one that is incredibly small, incredibly cheap and incredibly quick to produce."

Making such devices using an inkjet printer, however, is still a far cry from printing high-quality logic circuits. That requires fabricating transistors and other electronic components at the scale of a few hundred nanometers—the level of precision in a Pentium chip. For that, Jacobson has made use of polymer stamps that don't look all that different from the stamps used to certify documents. In one version, the stamp has the architecture of the circuit in positive relief and is dipped in the nanoparticle ink; the circuitry is then transferred by hand onto a substrate. Also promising is a negative stamp that "embosses" a thin layer of ink previously deposited onto a plastic surface. The stamp's features push aside the ink at certain points, forming whatever feature is engraved on the stamp at resolutions of 200 nanometers.

Pentium Challenge

THIS IS ALL A MIGHTY ATTRACTIVE VISION. BUT CAN PRINTED electronics actually compete with multibillion-dollar fabs in making the exacting circuitry needed for high-quality logic? Sigurd Wagner, for one, doesn't think so. A professor of electrical engineering at Princeton University, Wagner is also pursuing research into printed inorganic logic, but he sees its promise in cheap electronics that can be used over large surfaces, not in taking on high-quality microprocessors.

His goal, says Wagner, "isn't competing with integrated-circuit technology; it's to go into an area that traditional integrated circuits can't handle." Attractive applications include wallpaper that acts like a giant display screen, electronics woven into textiles—even "electronic skin" covering an aircraft that is able to respond mechanically to changing conditions.

Jacobson agrees that the short-term payoff will come in producing the cheap, flexible electronics that could make such applications possible. "There are a huge number of applications for incredibly inexpensive, low-power disposable logic on plastic substrates," he says. And for now, Jacobson's printed circuits are better suited for these uses. For one thing, they are still far too slow for advanced logic applications; while Jacobson's inorganic transistors are an order of magnitude faster than the printed organic transistors made by Lucent and other research groups, they're still 100 times slower than the best inorganic transistors made from conventional techniques.

But making tomorrow's Pentium-like chips on a desktop fab remains the twinkle in Jacobson's eye. That will take increasing the speed of the printed inorganic logic. It's "likely a several-year research project," he says, "but we believe it's doable."

But for now, printed semiconductor chips are far too slow for advanced logic applications. But soon Joseph Jacobson hopes to speed up the inorganic transistors.

It's just the type of challenge and hugely ambitious project that Jacobson relishes. It is the type of project that makes you rethink the possibilities of a very familiar object. With E Ink, he is giving a new twist to a very old invention—the printed page. Rather than throw out the newspaper, Jacobson wants to preserve its virtues while updating it for the information age. And now he's rethinking the fabrication of integrated circuits. If Jacobson can make his visions of printed circuitry practical, he could change the meaning of "hardware" and replace the multibillion-dollar semiconductor fab with something not so different from the stamps that have been around for thousands of years.

While the rest of the computing industry attempts to drive down hardware prices through mass production of a few standardized chips, Jacobson is going in the opposite direction, trying to make every person the master—and manufacturer—of his or her own logic. ◊

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Remote remedy: At New York's Beth Israel Medical Center, a surgeon performs a heart operation sitting at a computer console.

RoboSurgeons

Their bedside manner is a tad impersonal. But the computer-assisted robotic systems finding their way into today's operating room may someday save your life. BY STEVE DITLEA

In the state-of-the-art hospital operating room, 67-year-old Eugene Bem lies anesthetized, pierced through the chest by three narrow, stainless-steel rods held by aluminum and plastic mechanical arms draped in translucent vinyl. Under way in the operating room is a critical portion of a heart bypass operation, but missing is the customary crowd of surgeons around the patient. Instead, in a corner across the room, a cardiac surgeon sits alone at a computer, his back to the operating table. Hunched over an enveloping, streamlined console, his feet tapping at pedal switches and fingers rapidly manipulating sensitive handheld controllers, the doctor in surgical scrubs could pass for some silent-movie mad scientist at his mighty Wurlitzer organ.

In fact, it's a day this past summer at New York's Beth Israel Medical Center, and cardiac surgeon Hani Shennib is offering a preview into the future of robotically assisted heart operations. Peering remotely into his patient's chest cavity via a tiny video camera mounted at the end of one of the three steel rods, the surgeon performs the delicate task of harvesting a chest artery to be used in a heart bypass graft. Still at the console, Shennib grasps, cuts and cauterizes using surgical instruments on the tips of the other two rods; the instruments, deep in the patient's chest, respond precisely to the physician's hand movements, which are relayed via a computer to the electromechanical arms.

Welcome to the future of the operating room. The computer-mediated part of this heart operation is still under clinical testing pending approval by the U.S. Food and Drug Administration. But just a few days prior to the Beth Israel procedure, the FDA approved the commercial sale of the computer-controlled robotics for abdominal laparoscopic surgery as well as minimally invasive gallbladder, prostate, colorectal and esophageal procedures—potentially 3.5 million operations a year in the United States.

With more than 50 advanced robotic systems already in hospitals around the world (the machines have previously been approved for sale in Europe and are in clinical trials in Japan), the robot-assisted operating room of tomorrow is just around the corner for many patients. Indeed, the cascade of robotic surgery "firsts" proclaimed by hospitals in the United States and abroad became a torrent after the FDA's initial commercial approval.

The day after the FDA announcement, for example, Henrico Doctors' Hospital in Richmond, Va., publicized the first non-clinical-trial use of robotic surgery for a gallbladder removal; the operation was performed by surgeon William E. Kelley with a da Vinci system on 35-year-old Kimberly Briggs. To demonstrate just how nontraumatic the procedure could be, less than four hours after her operation was over Briggs was wheeled into a press conference, where she told reporters, "I feel great."

The potential advantages of the robotic systems are dramatic. The robotic arm positions and holds the video camera with greater accuracy and steadiness than any human being could. Seated comfortably instead of standing over the patient, the surgeon is less subject to stress and fatigue—a critical factor during procedures that can last many hours. Should there be a tremor in the surgeon's hand, as there could be during a long operation, the computer filters it out. There's an expression for this robotic version of a steady hand: "virtual stillness."

The technology also holds the promise of making minimally invasive operations, in which surgery is performed through small incisions, available to a far larger group of patients. Minimally invasive techniques mean less trauma for the patient and have become common for such operations as gallbladder removal. In today's more conventional version of minimally invasive surgery, long-stemmed, narrow instruments are directly controlled by the surgeon; it's somewhat like using chopsticks to perform surgery. Because of the special training required and limits to its applicability, this form of surgery is practiced by fewer than one-third of U.S. surgeons. Thanks to computer-assisted procedures that are more exact and reproducible, a new generation of minimally invasive techniques could make less trauma for the patient the norm rather than the exception.

In the case of cardiac operations, these advances mean the surgeon is able to spare the patient the trauma and pain involved in cracking open the breastbone and using a heart-lung pump while the heart is stopped. In fact, Beth Israel heart patient Bem was released the next day instead of after the weeklong hospital stay (at $1,400 per day) that is routine following open-heart surgery.

Hearts of Gold

Medical regulators in the federal government share the increasing enthusiasm for robotically assisted surgery. In approving the million-dollar da Vinci system made by Intuitive Surgical of Mountain View, Calif., the FDA gave the technology a verbal pat on the chassis. "This system is the first step in the development of new robotic technology that eventually could change the practice of surgery," said FDA Commissioner Jane E. Henney. At the same time, the FDA notified Intuitive Surgical's chief rival, Computer Motion in Goleta, Calif., that robotic surgery devices will be cleared for market release on an accelerated basis. This makes it likely that Computer Motion's $750,000 ZEUS Robotic Surgical System will also be approved by the FDA for sale for some procedures by sometime next year. (Like all medical devices, robotic surgery equipment must be approved by the FDA separately for each type of procedure.)

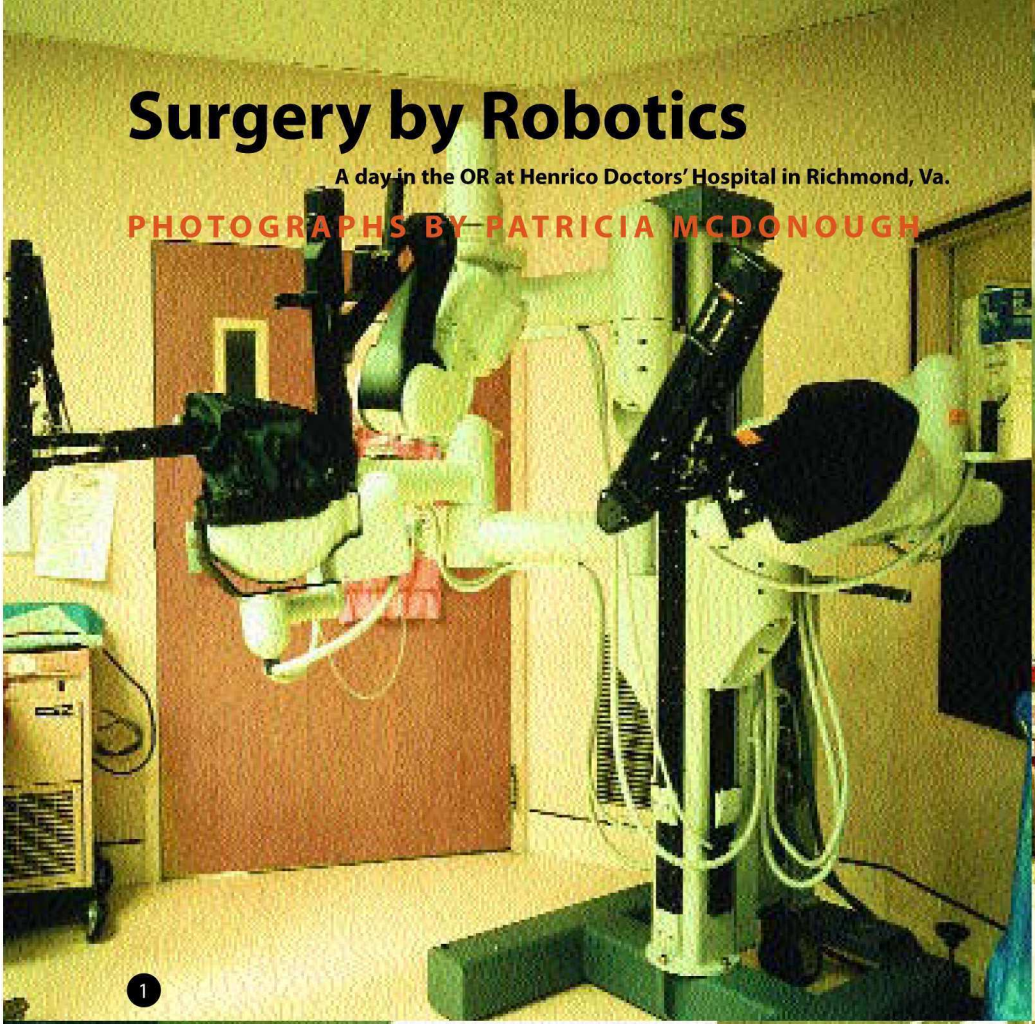
Given recent regulatory **approval,** **robotically assisted surgery** is just around the **corner** for many patients.

PHOTOGRAPH (PREVIOUS SPREAD): THE NEW YORK DAILY NEWS

Surgery by Robotics

A day in the OR at Henrico Doctors' Hospital in Richmond, Va.

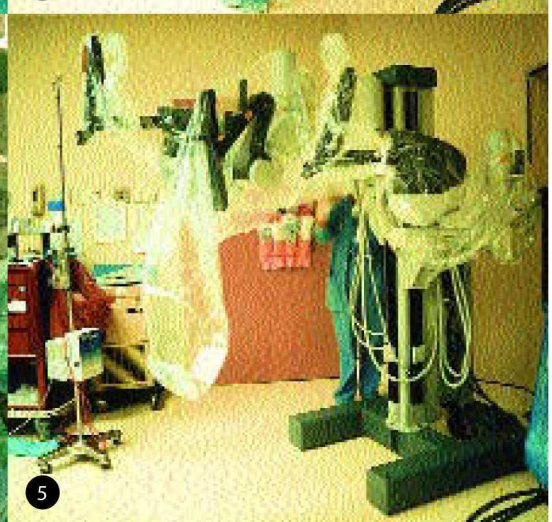
PHOTOGRAPHS BY PATRICIA MCDONOUGH











1 The da Vinci robotic apparatus waits in the operating room prior to a minimally invasive procedure for a patient with gastroesophageal reflux disease.

2 Surgical nurses hook up the endoscope, which uses twin cameras, to the video monitoring system.

3 One of the robotic arms, equipped with the narrow surgical instrument.

4 A nurse drapes the robotic platform with sterile covering.

5 Finally ready for surgery, the robotic apparatus patiently awaits the patient.

When it comes to robot-assisted surgery, however, the performance of cardiac procedures is the Holy Grail. More than 400,000 open-heart surgeries are performed each year in the United States, at a cost of nearly $20 billion. Both lifesaving and expensive (typically $25,000 per operation), open-heart coronary bypass surgery is often referred to as the "gold standard" by practitioners and hospital administrators.

Cardiac surgeons say the looming presence of robotics in the operating room could revolutionize the operations. "The integration of computers and robotics will have as great an impact as the introduction of anesthesiology into the operating room," said heart surgeon Ralph Damiano Jr., speaking at the recent Fourth International Congress on Computers and Robotics in the Operating Room, in Santa Barbara, Calif. At the same time, Damiano, who in 1998 was the first physician in the United States to perform robotically assisted heart bypass surgery, cautioned that the technology alone is not enough to guarantee wide-scale adoption of the techniques; operating-room economics apply too.

The challenge is to demonstrate that, in addition to reducing operating overhead with fewer personnel in the operating room and shorter patient hospital stays, robotic surgery will also result in improved outcomes over current methods, attracting even more patients. By focusing on heart operations, the manufacturers of the new surgical equipment are banking on this becoming the earliest area of wide adoption—and for good reason. According to Jan Wald, senior vice president for equity research at George K. Baum & Co., "the profit margin for hospitals is very low, only about 2.5 percent—no more than what supermarkets make. But cardiac surgery is very profitable; it's a big moneymaker in any hospital." Hence the anticipated market for high-priced, high-tech computer-assisted cardiac surgery systems, which are second in cost only to magnetic resonance imaging and other sophisticated medical imaging systems in today's big-ticket capital equipment for hospitals.

Robo Duels

GIVEN THE HIGH STAKES, IT'S HARDLY A coincidence that Beth Israel's and New York University's medical centers are among the facilities most aggressively pursuing the technology in cardiac surgery. "New York is one of the most competitive markets for heart care in the hospital business," says Richard Gemming, executive director of the Heart Institute for Continuum Health Partners Inc., which runs Beth Israel and a half-dozen other formerly independent hospitals in the vicinity. Due to consolidation and a New York State medical regulatory system that limits the number of cardiac centers, a few operating rooms must vie for the area's large and sophisticated patient population; if a healthcare facility falls below a mandated number of operations necessary to maintain surgical expertise, the hospital can lose its cardiac approval.

In this atmosphere of intense competition, it's also not surprising that Beth Israel and NYU are adopting rival equipment—da Vinci and ZEUS systems. In principle, the hardware is similar, consisting of a computer-mediated surgical workstation with a high-quality video display and hand-input devices, a wired network to communicate surgeons' gestures, and a cart bearing the system's robotic arms. In practice, however, da Vinci and ZEUS differ in crucial ways.

By design, da Vinci's console is meant to be immersive: The surgeon looks down at a three-dimensional view of the patient's innards, as picked up by a two-chip charge-coupled device (the same type of chip used in digital cameras) video element in the scope at the end of one of the stainless-steel rods. To assure a top-notch, stereoscopic, nonfatiguing view, mirrors reflect images from two full-sized monitors, hidden within the bulky console, into the left and right eyepieces of the visor port.

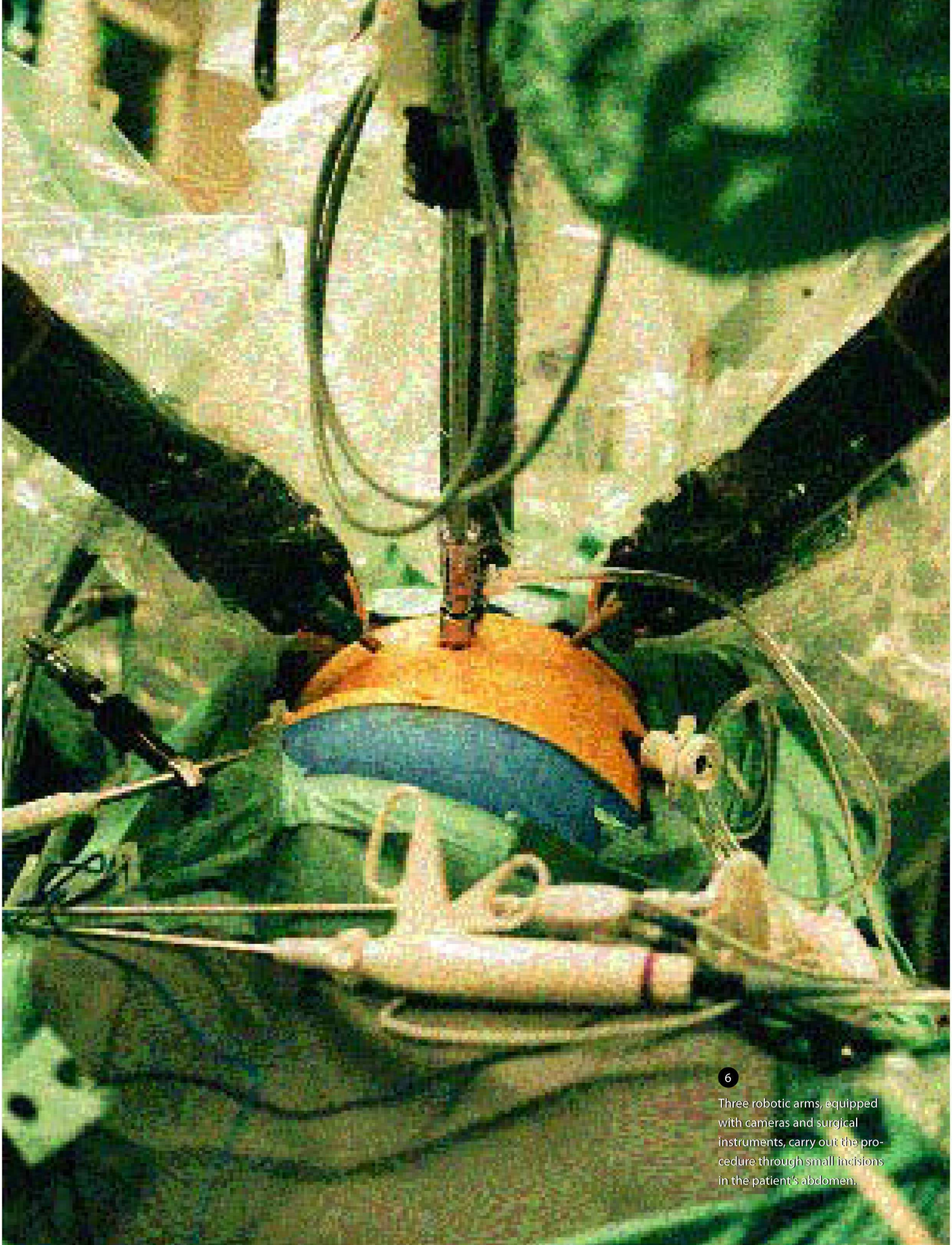
By contrast, the ZEUS console is more like a computer workstation: The surgeon sits opposite a vertical screen—available with 3-D stereo imaging using lightweight polarizing glasses. An in-depth display, it turns out, may not be as crucial as the subtle color cues available from monocular high-definition video, especially at 10 times magnification, which is beyond the augmentation afforded by simple optics worn by a non-robotically assisted surgeon.

For the heart surgeons, both types of high-quality displays make it possible to see anatomical features in precise detail. "You can see anatomical structures you've never seen before," says NYU's Eugene Grossi; as director of the hospital's cardiovascular research laboratory he was responsible for adding a Sony high-definition TV system to the ZEUS equipment. Says Beth Israel's Shennib of his da Vinci console: "It's the best medical visualization I've ever seen."

Beyond the displays, other key differences can be found in the systems' hand controllers and coupled robotic arms and instruments. ZEUS replicates the endoscopic instrumentation used in conventional minimally invasive surgery. (An endoscope is a slender optical tube passed into the body to allow the surgeon to view an operation.) The surgeon activates the long-stemmed chopstick-like instruments by compressing V-shaped handles. This control device, though perhaps not as intuitive as other types, involves a set of manipulations to which practitioners of minimally invasive surgery are already accustomed.

The da Vinci system adds another wristlike articulation to the instrument tips and an extra degree of freedom to its hand controllers. "It provides better dexterity. The motion is close to having your hand inside the patient," says Shennib. But not exactly. The da Vinci's force feedback, a computer-synthesized tactile resistance felt by the surgeon when making an incision or sewing a suture, provides a cue to instruments' actions but doesn't accurately replicate what is sensed in hands-on work. According to Shennib, "You feel resistance from the [robotic] arms when you're pushing on the controls, but not the delicate feedback of pulling or pushing on tissue."

High-quality **displays** used with the **robotic systems** make it possible to see anatomical features in **precise** detail.



6

Three robotic arms, equipped with cameras and surgical instruments, carry out the procedure through small incisions in the patient's abdomen.

Grinding to a Start

WHILE CARDIAC SURGERY AT TWO OF Manhattan's leading medical centers may be the high-profile payoff of robotic surgery today, the technology's roots are less glamorous. Incorporating robotics into surgical procedures began at academic institutions including MIT, the Carnegie-Mellon Institute and several campuses of the University of California. In 1986, the University of California at Davis and IBM's Thomas J. Watson Research Center joined forces to begin development of computer-assisted hip replacement surgery; by 1992, a spinoff of that effort, Integrated Surgical Systems, introduced the Robodoc Surgical Assistant System.

The job of this robotic system is to grind away bone. At best, conventional surgical techniques leave gaps of 1 millimeter or more between bone and implant, but no more than 0.5 millimeters of bone will grow out from a cut bone. The insurmountable space eventually leads to implant failure. Milling bone with greater precision than an experienced surgeon could, Robodoc assures that a cementless prosthesis can achieve long-term fixation by allowing bone to grow into the porous coating of the implant. In fact, this March, Integrated Surgical reported that Robodoc had been used for the first total knee replacement performed using robotic surgery.

But grinding down hips and knees doesn't fire the public imagination like mending an ailing heart. With the goal of aiding in complex procedures such as heart operations, companies developing robotics have come up with increasingly sophisticated systems. In 1994, Computer Motion produced the first FDA-cleared robot for assisting surgery in the operating room—the Automated Endoscopic System for Optimal Positioning, or AESOP. AESOP is essentially an electromechanical arm for positioning an endoscope. Two years later, voice control by the surgeon was added, allowing for exact, hands-free control during an operation. In 1998, Computer Motion introduced ZEUS, its robotic surgery system capable of operating on everything from an ailing heart to an inflamed gallbladder.

Rival technology underlying Intuitive Surgical's da Vinci system grew up around the same time, financed by government funding for research in "tele-surgery"—computer-assisted medical procedures delivered at a distance. In the early 1990s, SRI International in Menlo Park, Calif., was one of several institutions receiving grants from the Department of Defense's Advanced Research Projects Agency to develop tele-surgery. A prototype system was built and proved an inspiration to Frederic Moll, who co-founded Intuitive Surgical in 1995 and is now the company's medical director. "What got me excited wasn't the remote-surgery aspect," Moll recalls, "but the way the system eliminated the need for a hand to be directly connected to a surgeon's instruments. It offered new ways of solving the challenges in minimally invasive techniques."

Tele-surgery could give an accident victim on a desolate highway **remote access** to **world-class** surgeons at major medical facilities.

Doctors on Call

WHILE RESEARCH INTO TELE-SURGERY helped to jump-start robotics in the operating room, distant operations have remained an elusive application. However, it may eventually prove to be one of the most significant uses of robotic surgery.

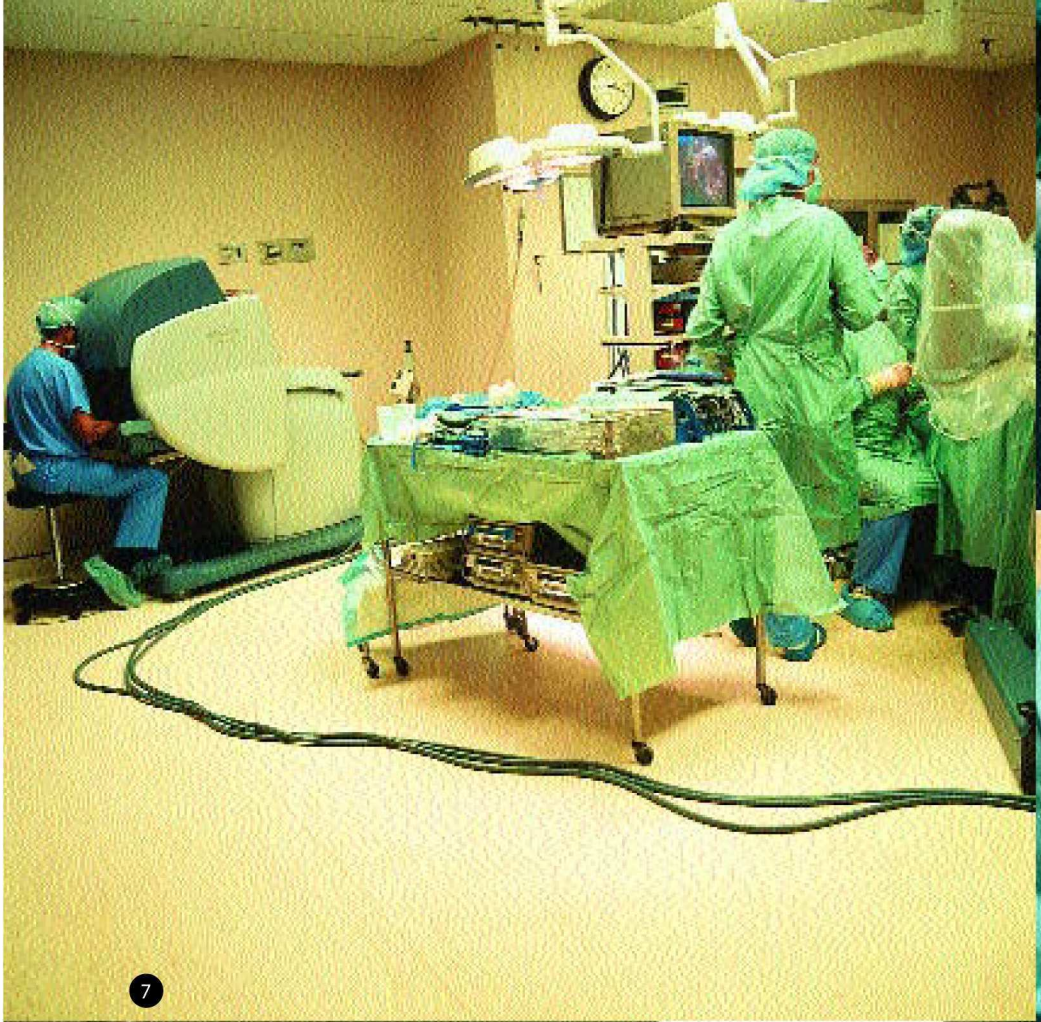
With either da Vinci or ZEUS, a surgeon seated across the room from the patient could as readily be operating from another room down the hall or from an office across town. Without having to spend hours traveling and prepping for each surgery, a specialist could perform procedures in several different operating rooms scattered throughout a region on the same day. At least that's the theory. In practice, there are limits, including ones caused by what can be a disorienting lag time between a surgeon's hand motions and the robotic arms' actions. Due to transmission delays over longer distances, the maximum effective range seems to be about 30 miles by wireless communication and 200 miles via a cable connection. The unreliability of network communication infrastructures presents even more of an obstacle—at least for now.

At NYU Medical Center one morning this August, surgeon Stephen Colvin is operating on the heart of a 56-year-old woman to repair a damaged mitral valve. The physician is working by hand with endoscopic instruments, while invoking robotic help to position the scope that is relaying the close-up view to a video monitor hanging above the patient. "AESOP!" he says. There's a trill of acknowledgment from the machine. "Move back. Up. Up." The scope moves to the proper orientation.

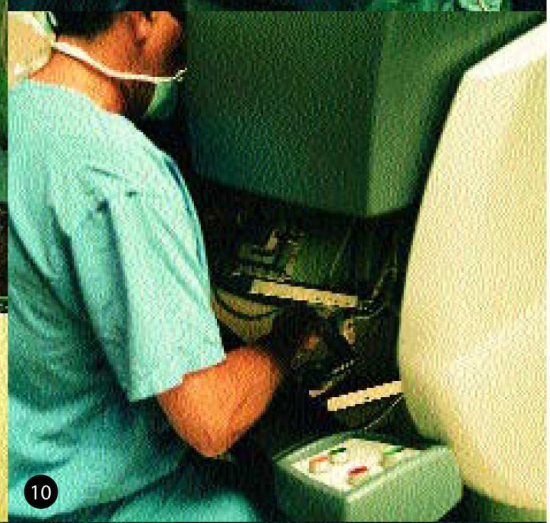
In the hallway outside the operating room, Grossi leads an audiovisual team televising the operation via satellite uplink to a medical conference in Montana. Eventually, interns and doctors at remote teaching venues could experience the actual surgical motions of their world-class colleagues on force-feedback-equipped simulators. At the moment, however, maintaining video communications is a difficult enough challenge. At the operation's most critical phase, the TV signal is lost on the downlink in Montana. (A burst of radiation from a microwave oven on the conference's premises apparently knocked out today's lesson.)

While tele-surgery may not yet be ready for prime time, it's only a temporary setback. Next time, the physicians will use broadband telephone lines to secure a steady transmission link. And soon they expect to televise a complete robotically assisted surgery. In such increments, tele-mentoring and tele-surgery will advance—further accelerating development of computer-enhanced procedures. It will take significant improvements in communications networks, but in perhaps the not too distant future, an accident victim on a rural highway in Nebraska, or a heart patient in an isolated village in France, could have remote access to care by the finest world-class surgeons at major medical facilities.

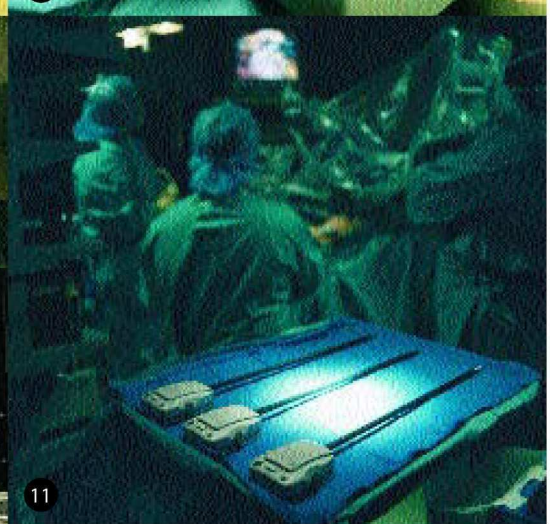
With the enabling technology for robotic surgery already making an impact in the operating room, it's just a matter of time before a surgical star "phoning in" a complicated procedure is a routine event in the operating room. ◊











7 The "real" surgeon, William Kelley, manipulates the surgical instruments from a console in the corner of the OR.
8 Nurses follow the procedure on a video monitor.
9 Nurses are ready to make any needed adjustments.
10 The surgeon guides the robotic instruments from the console.
11 The surgical instruments used by the da Vinci robotic system alleviate hand tremors.

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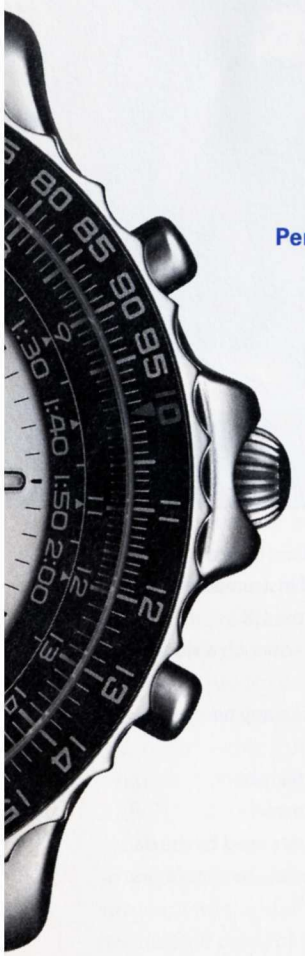
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"Terayon Communication Systems, the broadband networking company, priced a highly successful convertible via Deutsche Banc Alex. Brown. The lead increased the deal from $400 million to $500 million and still had a book that was four times covered. The bonds were priced at the bottom of the 5% to 5.5% yield to maturity range and in the middle of the 22% to 26% conversion premium range. The stock had moved up 7% over the marketing period, outperforming the Nasdaq."

International Financing Review, July 22, 2000

Deutsche Bank

BIOTECH SPEEDS ITS EVOLUTION

A HANDFUL OF HOT STARTUPS ARE EXPLOITING NATURE'S OWN METHODS—VASTLY ACCELERATED—IN ORDER TO BREED BETTER DETERGENTS, DRUGS AND CROPS. BY KATHRYN BROWN



TO CATCH A GLIMPSE OF EVOLUTION, PIM STEMMER DOESN'T HAVE TO SET SAIL FOR THE Galapagos. He needn't trudge through the Costa Rican rain forest or blast into Antarctic sea ice. For a front-row view of evolution in action, Stemmer simply walks over to a lab bench at Maxygen, a biotech startup in Redwood City, Calif., where he oversees research and development. At Maxygen, researchers are tapping evolutionary principles to "breed" new proteins, successively fine-tuning specific traits—say, heat tolerance or the ability to stick to a cancer cell—by tinkering with the underlying genetic code and selecting only the best of the new genes for the next round of improvement.

In farm fields and kennels, exploiting evolution is old hat. Farmers favor a corn crop that best survives summer, for instance, and with decades of patience, breeders can produce dogs as specialized as poodles and Pomeranians. But in the lab, evolving better proteins is a recent feat—and a faster one. By focusing their efforts at the genetic level, one molecule at a time, researchers can coax a protein toward perfection in just a matter of weeks. In the process, companies like Maxygen hope to crank out safer medications, more potent cleansers and healthier crops. Just a few years out of the gate, these young firms are already bringing new protein products to market, forging alliances with such giants as Dow Chemical, DuPont and Novartis and launching successful IPOs *(see "Evolving Industry," p. 88)*—all evidence that "directed evolution" is really happening, not just in the test tube, but also in the marketplace.

PHOTOGRAPHS BY BROMBERGER & HOOVER

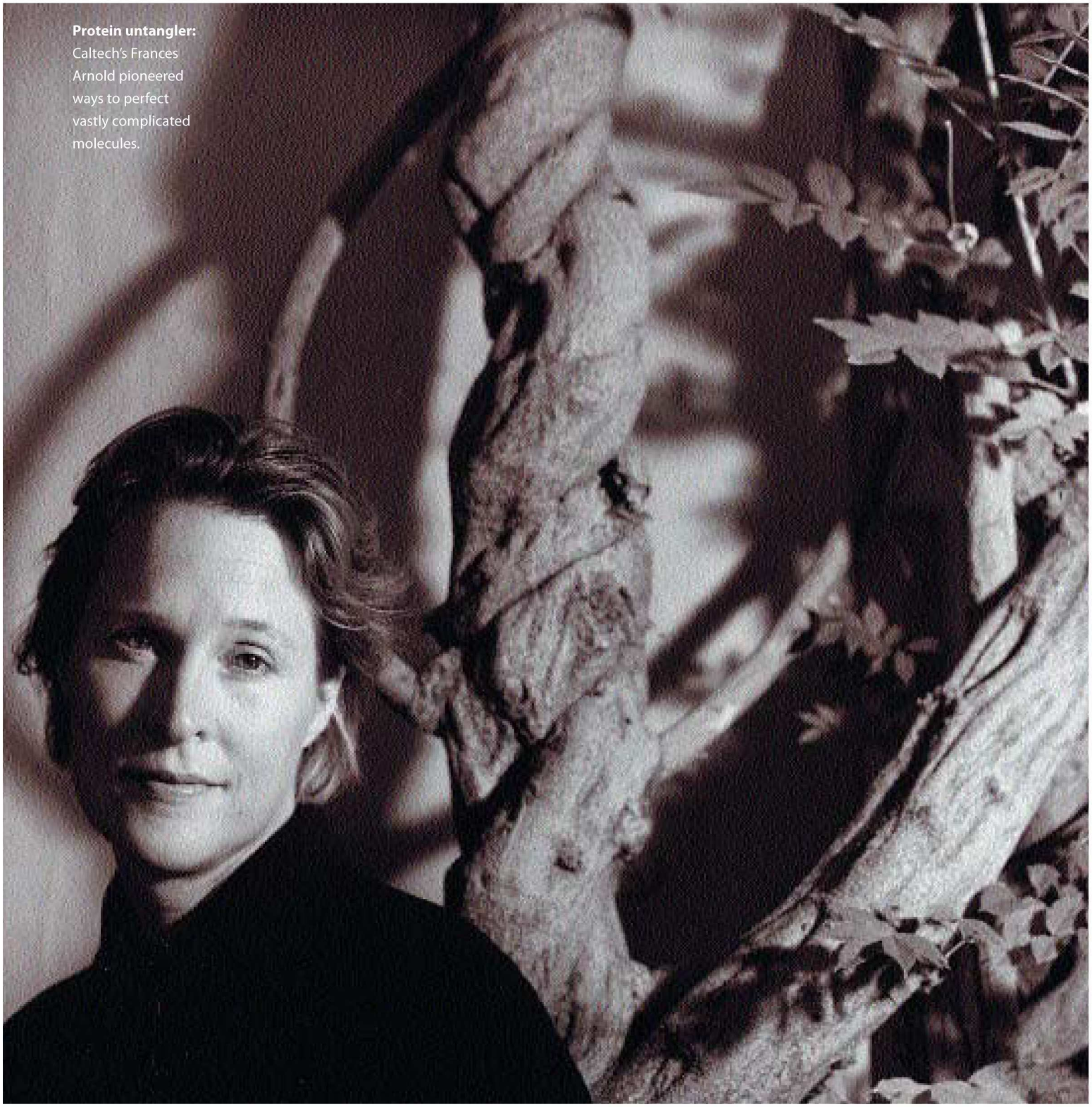


The director: Pim Stemmer heads up R&D at Maxygen, a firm devoted to directed evolution.

Evolutionary Alternative

DIRECTED EVOLUTION IS AN ALTERnative to "rational protein design," a technique that became popular in the 1980s. In rational protein design, researchers try to craft a new molecule—perhaps an antibody or an enzyme—by first studying an existing protein's structure and then modifying it via targeted mutations to the gene that encodes it. But that sort of painstaking methodology can prove to be difficult. Not only must researchers determine the sequence of amino acids—the 20 building blocks that make up all proteins—but they must also understand the complicated pattern of folding that the chain of amino acids undergoes to become a functional, three-dimensional molecule. Even after bringing sophisticated computer tools to bear on the problem, researchers say, it's hard to unravel the workings of a protein folded up like origami, much less create a new one that behaves the way you want it to. "Rational design has failed miserably at helping us make useful proteins," says Caltech's Frances Arnold, a directed-evolution pioneer who sits on Maxygen's scientific advisory board.

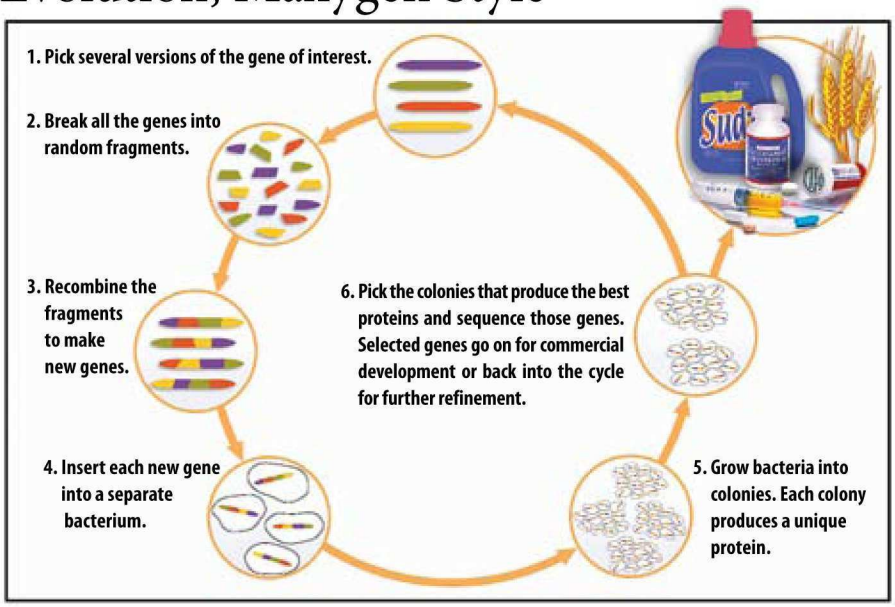
Frustrated with the limitations of rational design, a growing group of researchers are borrowing from nature's tool kit instead, mimicking the basic processes of evolution—the generation of genetic diversity and the selection of desirable traits—to improve proteins, even without understanding their complicated structures. And turning to nature



Protein untangler: Caltech's Frances Arnold pioneered ways to perfect vastly complicated molecules.

can pay off quickly. A team led by MIT chemical engineer Dane Wittrup, for example, evolved an antibody fragment to bind 10,000 times more tightly to its target in just four rounds of directed evolution. Researchers like Wittrup hope better-binding antibodies might someday be used to fight cancer: Attach a cell-killing agent to an antibody that binds specifically and tightly to molecules found only on cancer cells, the logic goes, and you can wipe out the cancer without damaging healthy tissues. And it's not just antibodies but a wide range of potentially useful proteins—from industrial enzymes to protein pharmaceuticals—that stand to benefit. "With just a few evolutionary cycles, we can dramatically improve molecules that have frustrated companies for years," says Stemmer.

Evolution, Maxygen Style



BETSY HAYES

Do the Shuffle

Stemmer invented his version of directed evolution, called "molecular breeding," seven years ago, while working at Affymax, in Palo Alto, Calif. The brainchild of entrepreneur Alejandro Zaffaroni, Affymax was the first company to focus exclusively on discovering new drugs through combinatorial chemistry—a shotgun approach in which huge libraries of unique molecules are randomly generated, and then the useful ones are fished out through clever screening. Extending the combinatorial idea into the realm of protein development, Stemmer struck upon the idea of shuffling DNA. The basic concept: Start with a few different versions of the gene for a protein you'd like to improve, cut them up and mix the pieces together to generate a diverse pool of new versions of the gene, fish out the ones you like best, and start all over again *(see "Evolution, Maxygen Style," above)*. In 1997, Zaffaroni spun off Maxygen to take molecular breeding to market.

Larger companies, sniffing the commercial potential of evolution in a test tube, began hooking up with Maxygen. One of the first was the Danish firm Novo Nordisk, the largest industrial enzyme maker in the world, which had already been dabbling in directed evolution on its own. Reporting last year in the journal *Nature Biotechnology,* scientists from the two companies showed how directed evolution might churn out a new laundry detergent enzyme. The researchers began with the structural gene for Savinase, a stain-eating enzyme developed by Novo Nordisk. Next they collected DNA for the naturally occurring version of the enzyme, subtilisin, from 25 different strains of *Bacillus* bacteria. With scissors-like enzymes, the team chopped up Savinase and wild subtilisin DNA, shuffling it together to create a new generation of unique "daughter" genes. Then the researchers inserted each gene into a bacterial cell. Finally, they exposed those cells to different temperatures and pHs to see how the resulting proteins held up.

USING EVOLUTION CAN **IMPROVE** PROTEINS THAT HAVE **FOILED** RESEARCHERS **FOR YEARS**

The results were intriguing. While Savinase works best in a limited range of conditions—cool water and a fairly alkaline environment—some of the new proteins produced by the experiment worked four times better, and under acidic conditions. Many of the daughter molecules also performed better than their parents when heated or dunked in organic solvents. For 35 years, Stemmer notes, teams of industry scientists have tried to rationally design an improved subtilisin enzyme. "Within a year, three of our scientists turned out a much better molecule," he says.

Celebrate Diversity

And who couldn't use a better molecule? Analysts say the market for directed evolution stretches wide, including medicine and agriculture in addition to the chemicals industry. "This is no fad," says David Molowa, a biotech analyst at Chase Manhattan in New York. "I think this technology is very real, and it's already generating new products." This list today includes a potential new catalyst for penicillin production, developed by Maxygen and now in commercial development at Dutch conglomerate DSM, and a fat-stain-removing enzyme from Novo Nordisk called Lipoprime, already on the market.

Indeed, the $2 billion industrial enzyme market is a logical niche for directed evolution, says Carolyn Fritz, global director of industrial biotechnology for Dow Chemical. Fewer than 30 enzymes generate more than 90 percent of industrial enzyme sales. That's not for lack of trying on the part of the chemical companies to make new ones. The problem is that most enzymes fizzle under

harsh, real-world conditions. Manufacturers could use new enzymes to make everything from paper to ethanol, low-cholesterol cooking oils and blue jeans. "We have a lot of different customers who could use better enzymes," Fritz says.

To bring those enzymes to life, Dow has partnered with another biotech firm, San Diego-based Diversa, which has a different take on directed evolution from Maxygen. Rather than starting with a few different versions of a gene and shuffling the DNA, Diversa researchers typically begin with one gene and then introduce a multitude of mutations.

This technique generates maximum diversity in the pool of new candidate proteins. Indeed, using a procedure called "gene-site saturation mutagenesis," Diversa researchers can try each of the 20 possible amino acids in each position along the protein chain—in less than two weeks. "It's a numbers game," says Dan Robertson, head of enzyme technology at Diversa, a game the company hopes will yield hardier and more effective proteins.

Diversa researchers stack the odds in their favor by choosing unusual genes as starting points. The company has hired far-flung scientists to collect microbes from extreme locations—the gut of a bug from the Costa Rican jungle, an industrial dump site or the rotting skin of a submerged whale carcass. By harvesting DNA from bacteria on that dead whale, Diversa scientists collect the raw genes for enzymes that naturally break down polymers or fats in nasty environments. "If we need a high-temperature enzyme to work under an alkaline pH, we go looking for places that already have those kinds of conditions," explains Diversa CEO Jay Short. "We discover enzymes that are optimal in those settings, and then we can use directed evolution to push favored traits even further."

SOME PROTEINS WORK PERFECTLY IN THE LAB, BUT FALL TO PIECES UNDER REAL-WORLD CONDITIONS

Short says Diversa hopes to spread its discoveries around, selling improved proteins for everything from animal feed to human medicine. "I think directed-evolution tools are going to be very important for evolving human therapeutics—increasing a drug's binding affinity or its half-life, or lowering the dosages necessary for it to work," Short says.

Diversa isn't the only evolutionary firm sizing up the $300 billion worldwide pharmaceuticals market. After working on enzymes for the oil industry, Enchira Biotechnology of The Woodlands, Texas, is moving toward crafting antibiotics and drugs that fight cancer, says Peter Policastro, company president. San Diego's Applied Molecular Evolution is packing an extra punch into existing drugs by changing their protein structures, evolving more powerful medicines. Currently, AME is partnering with Gaithersburg, Md.'s MedImmune to churn out second-generation versions of several MedImmune drugs.

For now, Chase Manhattan's Molowa says that directed-evolution firms will continue to sell themselves as technology-platform providers, partnering with industry giants that promise dollars and distribution. In addition to its deal with Novo Nordisk, Maxygen has forged collaborations with DuPont subsidiary Pioneer Hi-Bred, AstraZeneca and others—and has "proof-of-principle collaborations" with Abbott, Pfizer and Novartis under way. Diversa has joined forces not only with Dow, but with Novartis and Rhone-Poulenc, among others, as well. Eventually, Molowa adds, look for firms like Maxygen and Diversa to roll out their own products.

White Potato, Red Potato

As in nature, however, evolution in the lab can be a bumpy ride. Some researchers caution that the new technique has its limitations. "You're not going to turn a potato into a broccoli," says Arnold at Caltech. "Maybe you can turn a white potato into a red potato. The question is, what's close, in terms of evolution? We just don't know yet."

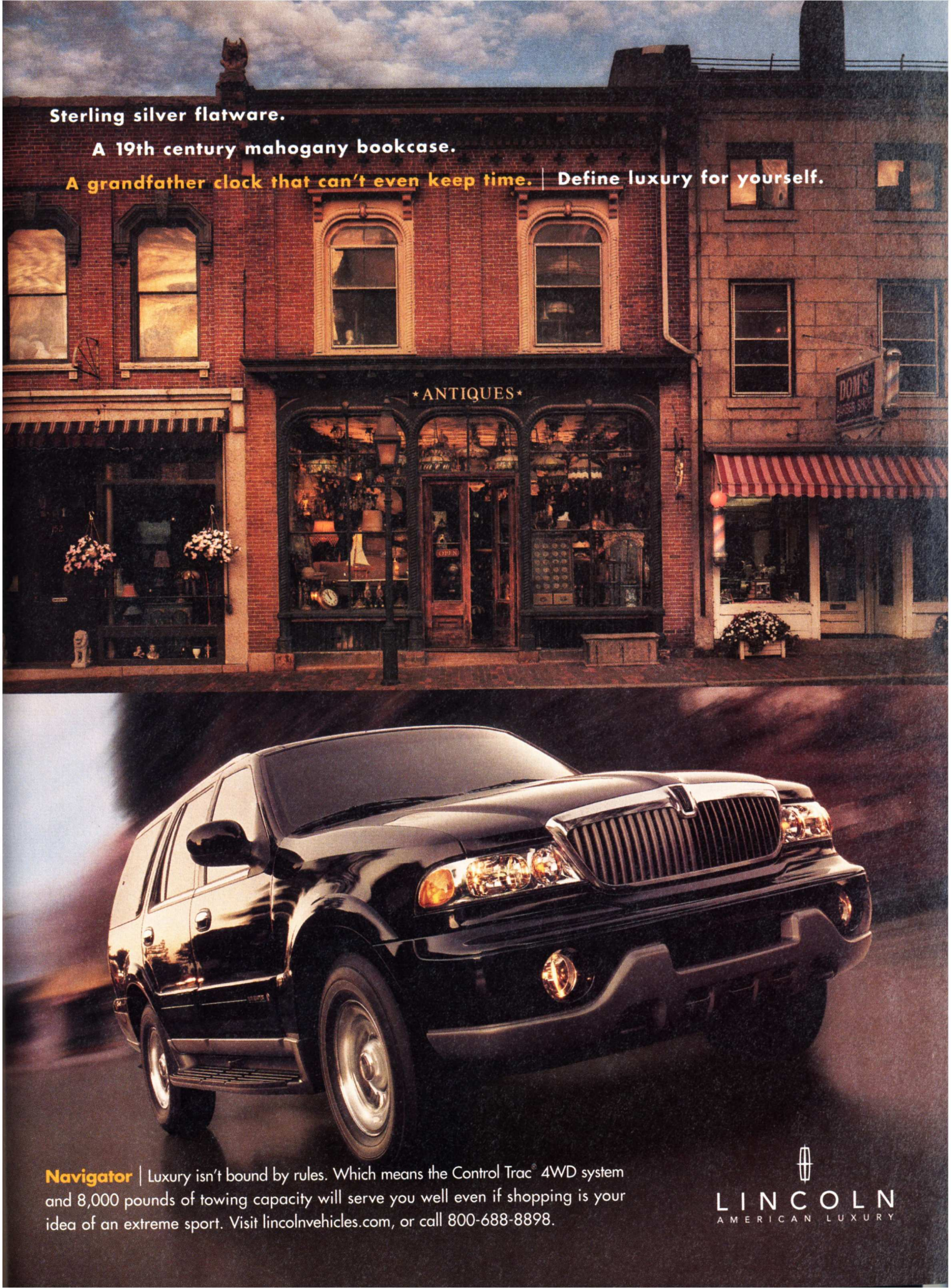
It's a question lacking easy answers. At Maxygen, company president Simba Gill says DNA shuffling has worked in 90 percent of experiments—and the firm drops the experiments that fail. Duke University biochemist Homme Hellinga says he would like to see chemists combine aspects of rational protein design and directed evolution, using computers to model new proteins and then testing well they can adapt to different environments.

Evolving Industry

Five companies directing evolution

COMPANY	YEAR OF IPO, DOLLARS RAISED	CLAIM TO FAME	MAJOR PARTNERS
Applied Molecular Evolution San Diego, Calif.	2000, 88 million	Teaching old medicines new tricks	MedImmune
Diversa San Diego, Calif.	1999, 174 million	Improving on nature's extremes	Dow Chemical, Novartis, Aventis
Enchira Biotechnology The Woodlands, Texas	1993*, 16 million	A new push toward pharmaceuticals	Genencor
Maxygen Redwood City, Calif.	1999, 96 million	Molecular breeding	Novo Nordisk, DuPont/Pioneer Hi-Bred, AstraZeneca
Novo Nordisk Biotech Davis, Calif.	——	R&D subsidiary of Novo Nordisk, the world's largest maker of industrial enzymes	Maxygen, UC-Davis

*Enchira was then known as Energy BioSystems.


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Going to extremes: Diversa CEO Jay Short's company looks for new genes in far-out places.

But even proteins that evolve beautifully in the lab face classic development hurdles, warns Arnold. When Arnold's lab evolved a detergent enzyme for Procter and Gamble, the new enzyme passed lab tests with flying colors—only to fall apart inside company washing machines. "You can't mimic a washing machine in a high-throughput screen," Arnold says. "You eventually have to try it." In the same way, she adds, companies such as Diversa and Maxygen will have to prove that each of their evolved molecules works in the real world.

Yet another obstacle could crop up in an arena that is becoming central to almost all of high technology these days: intellectual property. Both Maxygen and Diversa have staked relatively broad patent claims, which some industry observers say might not survive litigation. And a patent issued to AME in 1998, if broadly interpreted, might force some players in the field to seek licenses from AME in order to continue their projects. AME set up a licensing program this spring and has already successfully defended its patent against one challenge in Japan. Regardless of how the legal landscape shapes up, though, directed evolution seems certain to offer researchers in academia and industry alike a faster route to better proteins for years to come. ◊



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Lucent Ventures Into the Future

BY ROBERT BUDERI

Researchers from Bell Labs are taking company ideas and using them to start new businesses, some of which could threaten Lucent's established product lines. So what's the company doing about it? Supporting them every step of the way.

WHEN MATHEMATICIAN RAJIV LAROIA JOINED BELL LABS IN the summer of 1992, he thought he had found his ideal niche—if not for life, then at least for a comfortably long time. Armed with his new doctorate and a passion to make his mark, he reported to the Mathematical Sciences Research Department, where he found a sweet opportunity to work with world-class mathematicians, engineers and statisticians. "There was no specific charter," Laroia relates. "We were given sort of free rein to do anything we wanted to do." Bent on first broadening his horizons, he dived into the basics of communications—wireless, optics, theory and more. Laroia envisioned writing papers and contributing to state-of-the-art systems. But he didn't foresee leaving AT&T's (now Lucent's) illustrious research division—especially not to start a company. He wasn't an entrepreneur.

What a difference a few years and the age of Internet fever can make. Early this year, Laroia did the once inconceivable by helping found Flarion Technologies, which is out to make ubiquitous, wireless data access so affordable that a vacationing California family of four could tool along a Maine highway and simultaneously be surfing the Web, listening to the Oakland A's over the radio, watching *The Simpsons* and sending e-mail—all without denting the budget. It turned out Laroia's horizon-broadening pursuits had engendered a novel idea about how to achieve such wonders, an idea so far outside the conventional wireless paradigm that it couldn't find a ready home at Lucent. So Laroia convinced his whole five-person team to come with him to start Flarion. Job security went out the window. In exchange for equity, people took pay and benefit cuts. Bye-bye Bell Labs.

ILLUSTRATION BY GENE GREIF



Only not quite. Laroia and friends may have left their jobs to pursue technology that could, if it pans out, usurp a piece of their former employer's business—but it's all been done with Lucent's blessing and support. In fact, Flarion's launch was spearheaded by Lucent's three-year-old New Ventures Group (NVG), a division chartered to scout out Bell Labs technology that doesn't mesh well with current business lines, help researchers develop financial plans, attract venture capital and get the innovations out the door. The expectation is that these emigrant technologies will either go it alone or acquire enough critical mass to thrive inside Lucent, if repurchased by the mother ship. In this way, the company hopes to strengthen an Achilles' heel of any big firm: the effort to capitalize on "disruptive" or "white space" advances that buck the status quo—even if those new technologies spring from in-house research. Explains Bell Labs President Arun Netravali, "If you try to nurture that new thing in the same organization, with that same set of people who are today managing fairly substantial businesses using older technology, it becomes very difficult for this new thing to get much attention."

So far, Lucent's New Ventures folks have kicked off at least 24 other efforts designed to complement or compete with established business lines—raising $150 million in outside venture capital, not to mention the company's own contributions of roughly $225 million, to nurture these enterprises in a more focused and friendly environment. Three have now been brought back to the parent corporation, and one (the Internet multicasting concern Talarian) has gone public, with several additional IPOs planned for 2001—and the endeavor's success is setting the tone for similar efforts around the globe. But that's only the half of it. As *Technology Review* inaugurates its first Corporate Research & Development Scorecard, tracking spending trends in 150 leading technology-oriented corporations *(see p. 99)*, NVG's very existence underscores a critical point: There's far more to research and development spending than meets the eye. Indeed, while the Scorecard nicely reflects the current robust state of corporate health—especially among U.S. firms—it's only by looking beyond the numbers to programs like New Ventures that it's possible to get at the important changes that have reshaped the industrial research landscape in recent years.

Going for Growth

IN THE LATE 1980S AND EARLY 1990S, WHEN MANY FIRMS WERE mired in heavy losses, managers at AT&T (Lucent's progenitor), IBM, General Motors and other technology-intensive firms slashed R&D funding as they struggled to manage resources more efficiently. Now, as indicated in *TR*'s Scorecard and government statistics that show U.S. R&D funding rising steadily since 1994, budgets are steaming to new highs. But that hardly means it's business as usual inside the labs. Indeed, rapidly fusing fields such as computers and communications are bringing ever more competitors to the fore, putting an even greater premium on streamlining the R&D pipeline. To spur collaboration, reward game-changing ideas and, above all, get things to market more quickly and in better shape, a host of new programs, initiatives and interindustry collaborations have emerged.

New-ventures groups like Lucent's exemplify the current climate, in the sense that they mark an attempt to go beyond existing product lines into areas where the parent firm may be weak. Indeed, although the vast bulk of corporate R&D resources still go toward protecting existing businesses and product lines, firms are increasingly looking for fresh ideas and sources of growth. Nurturing these efforts from within, however, can be tricky. Corporate annals are replete with stories of ideas that got away from the home company because they proved too revolutionary or too far outside main business lines: Think Xerox's Palo Alto Research Center (PARC) and the litany of its 1970s personal-computing inventions—from the graphical user interface to WYSIWYG (what-you-see-is-what-you-get) word processing—that proved too much for the copier company to handle.

Xerox PARC may be the most famous, but every major firm has its own horror stories. That fact has led many to form a venture-capital-like entity to spin off promising ideas *(see "Out for a Spin," this page)*, in the hopes these upstarts will get a more friendly reception outside the company's confines. Indeed, a recent study by Harvard Business School Assistant Professor Henry Chesbrough traces these efforts to the 1960s, when one-quarter of the Fortune 500 companies operated venture arms. Almost invariably, however, these endeavors ended in abject failure—for reasons as diverse as the means of compensating

Out for a Spin

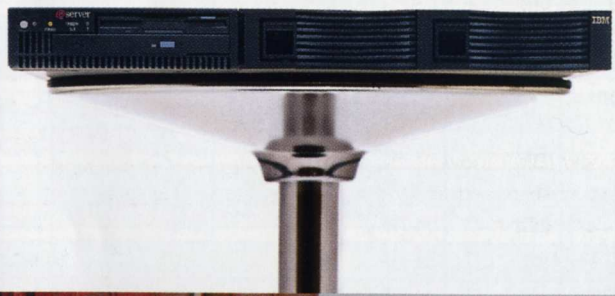
COMPANY	YEAR FOUNDED	SELECTED AREAS OF FOCUS	IDEAS SCREENED ANNUALLY	IDEAS SCREENED LAUNCHES	ANNOUNCED RECENT LAUNCHES
Intel New Business Development Group	1998	Data services, Internet hosting, networking, digital cameras and toys	100	2	**Vivonic:** fitness-planning software for handheld market **PassEdge:** digital-rights management for Internet streaming video
Lucent New Ventures Group	1997	Wireless, multimedia, e-commerce, networking, semiconductors	75	25	**Flarion:** wireless data **SyChip:** chips for wireless Internet appliances **CyberIQ:** Internet traffic and content management
Nortel Business Ventures Group	1996	Internet and networking technologies	150	NA	**Entrust:** encryption and digital security **Elastic Networks:** next-generation DSL **Netgear:** network computing **NetActive:** digital-rights management
Xerox Technology Enterprises	1998	Internet technologies	50	12 (est.)	**Inxight:** Web navigation and viewing software

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The Corporate Research & Development Scorecard

See how much 150 of the world's top companies invest in R&D.

COMPANY	2000* R&D SPENDING ($ MILLION)/RANK	% CHANGE FROM YEAR PREVIOUS*	2000* REVENUE ($ MILLION)	% CHANGE FROM YEAR PREVIOUS*	2000* R&D SPENDING AS % OF REVENUE/RANK	2000* NUMBER OF EMPLOYEES	2000* R&D SPENDING PER EMPLOYEE ($)/RANK
AEROSPACE							
BAE SYSTEMS (U.K.)	1,383/1	—	11,182	0.0	12.4/1	83,400	16,581/1
BOEING (U.S.)	1,341/2	−29.2	57,993	3.3	2.3/7	197,000	6,807/5
UNITED TECHNOLOGIES (U.S.)	1,292/3	−1.7	24,127	5.8	5.4/2	148,300	8,712/2
HONEYWELL INTL (U.S.)	909/4	130.7	23,735	0.8	3.8/4	120,000	7,575/4
LOCKHEED MARTIN (U.S.)	822/5	0.4	25,530	−2.8	3.2/5	147,000	5,592/6
RAYTHEON (U.S.)	508/6	−12.7	20,041	1.6	2.5/6	105,300	4,824/7
ROLLS-ROYCE (U.K.)	341/7	24.3	7,532	5.5	4.5/3	40,900	8,346/3
AUTOMOTIVE							
FORD (U.S.)	7,100/1	12.7	162,558	12.6	4.4/8	364,550	19,476/3
GENERAL MOTORS (U.S.)	6,800/2	−13.9	176,558	13.6	3.9/11	388,000	17,526/4
DAIMLERCHRYSLER (GER.)	5,703/3	15.4	149,084	13.8	3.8/12	466,938	12,213/7
TOYOTA† (JPN.)	4,562/4	9.7	119,356	9.2	3.8/13	—	—
VOLKSWAGEN (GER.)	3,765/5	25.6	74,715	9.5	5.0/6	306,275	12,294/6
HONDA† (JPN.)	2,917/6	9.0	58,335	3.9	5.0/7	112,200	26,003/1
BOSCH (GER.)	1,909/7	8.0	27,738	8.4	6.9/1	194,889	9,797/10
DELPHI AUTOMOTIVE (U.S.)	1,700/8	21.4	29,192	2.5	5.8/4	203,000	8,374/12
RENAULT† (FR.)	1,544/9	12.7	36,964	17.3	4.2/9	138,321	11,162/8
PEUGEOT CITROEN (FR.)	1,448/10	12.0	37,580	12.0	3.9/10	165,800	8,735/11
VISTEON (U.S.)	1,115/11	11.1	19,366	9.0	5.8/5	81,449	13,690/5
TRW (U.S.)	1,004/12	39.8	16,969	42.8	5.9/3	122,000	8,230/13
OPEL† (GER.)	928/13	—	15,379	0.9	6.0/2	44,636	20,779/2
MITSUBISHI† (JPN.)	684/14	−16.4	32,885	−6.0	2.1/15	—	—
VOLVO (SWED.)	529/15	−55.2	14,603	−41.3	3.6/14	53,148	9,945/9
BIOTECH							
AMGEN (U.S.)	823/1	24.0	3,340	22.9	24.6/9	6,400	128,563/6
GENENTECH (U.S.)	331/2	−10.2	1,332	25.4	24.9/8	3,883	85,262/8
CHIRON (U.S.)	254/3	9.2	763	3.5	33.3/6	3,110	81,575/9
SERONO (SWITZ.)	222/4	10.9	1,054	14.8	21.0/11	3,965	55,896/10
BIOGEN (U.S.)	221/5	24.8	794	42.5	27.8/7	1,351	163,696/3
MILLENNIUM PHARMACEUTICALS (U.S.)	160/6	40.0	184	37.4	87.0/4	985	162,312/4
GENZYME (U.S.)	156/7	31.0	772	8.9	20.2/12	3,800	41,040/11
INCYTE GENOMICS (U.S.)	147/8	35.7	157	16.4	93.5/3	—	—
IMMUNEX (U.S.)	127/9	5.6	542	122.5	23.4/10	1,170	108,275/7
SEPRACOR (U.S.)	122/10	94.1	23	122.0	540.2/1	377	324,668/1
GILEAD SCIENCES (U.S.)	113/11	49.9	169	11.8	66.8/5	760	148,537/5
ICOS (U.S.)	101/12	30.6	80	−28.1	126.3/2	392	256,482/2
CHEMICALS							
DUPONT (U.S.)	3,867/1	40.6	26,918	8.7	14.4/1	94,000	41,138/1
BAYER (GER.)	2,128/2	6.8	25,043	−10.2	8.5/2	120,400	17,676/3
BASF (GER.)	1,325/3	1.8	29,296	6.6	4.5/7	104,628	12,664/5
DOW CHEMICAL (U.S.)	851/4	−26.4	18,929	2.6	4.5/8	39,239	21,688/2
AKZO NOBEL (NETH.)	722/5	11.7	14,345	15.6	5.0/5	68,000	10,612/6
MITSUBISHI CHEMICAL† (JPN.)	629/6	−10.5	14,339	−11.6	4.4/9	—	—
SUMITOMO CHEMICAL† (JPN.)	515/7	9.3	8,685	−9.1	5.9/4	—	—
DEGUSSA-HUELS (GER.)	409/8	39.0	12,280	51.9	3.3/13	44,605	9,174/8
ASAHI CHEMICAL† (JPN.)	382/9	—	10,971	−8.6	3.5/12	—	—
MITSUI CHEMICALS† (JPN.)	364/10	43.1	8,013	25.6	4.5/6	—	—
ROHM & HAAS (U.S.)	341/11	64.7	5,339	43.5	6.4/3	21,512	15,852/4
PPG INDUSTRIES (U.S.)	324/12	19.6	7,757	3.3	4.2/10	33,800	9,586/7
IMPERIAL CHEMICAL INDUSTRIES (U.K.)	291/13	−17.9	13,414	−9.0	2.2/14	53,600	5,421/10
SOLVAY† (BELG.)	290/14	2.7	7,406	−3.3	3.9/11	33,864	8,571/9
COMPUTERS (HARDWARE)							
HITACHI† (JPN.)	4,650/1	−2.8	74,684	−5.2	6.2/9	328,351	14,163/11
IBM (U.S.)	4,575/2	2.4	87,548	7.2	5.2/12	307,401	14,883/10
FUJITSU† (JPN.)	3,699/3	2.0	49,085	5.2	7.5/6	—	—
NEC† (JPN.)	3,241/4	−9.2	44,558	−2.9	7.3/7	157,773	20,544/8
TOSHIBA† (JPN.)	2,965/5	−1.9	49,627	−2.9	6.0/10	198,000	14,975/9
HEWLETT-PACKARD (U.S.)	2,440/6	−27.3	42,370	7.5	5.8/11	84,400	28,910/6
MITSUBISHI ELECTRIC† (JPN.)	1,707/7	−7.7	35,520	−0.2	4.8/16	—	—
COMPAQ (U.S.)	1,660/8	22.7	38,525	23.6	4.3/18	67,100	24,739/7
SUN MICROSYSTEMS (U.S.)	1,383/9	36.4	11,726	19.8	11.8/2	29,700	46,573/2
XEROX (U.S.)	979/10	−6.1	19,228	−1.1	5.1/14	94,600	10,349/14
SANYO ELECTRIC† (JPN.)	878/11	−1.0	17,623	−2.2	5.0/15	—	—
SEAGATE TECHNOLOGY (U.S.)	668/12	−17.3	6,802	−0.2	9.8/3	82,000	8,146/16
EMC (U.S.)	573/13	81.6	6,716	23.5	8.5/4	17,700	32,346/4
DELL (U.S.)	486/14	132.5	25,265	38.5	1.9/19	36,500	13,315/12
NCR (U.S.)	403/15	−4.3	6,196	−4.8	6.5/8	32,200	12,516/13
QUANTUM (U.S.)	402/16	−9.1	4,727	−3.6	8.5/5	5,500	73,128/1
SILICON GRAPHICS (U.S.)	380/17	−17.2	2,749	−11.3	13.8/1	9,191	41,382/3
UNISYS (U.S.)	339/18	14.4	7,545	4.2	4.5/17	35,800	9,480/15
APPLE (U.S.)	314/19	1.3	6,134	3.2	5.1/13	9,736	32,251/5
COMPUTERS (SOFTWARE)							
MICROSOFT (U.S.)	2,970/1	18.7	19,747	29.4	15.0/9	31,396	94,598/2
CISCO SYSTEMS (U.S.)	2,065/2	27.9	12,154	43.2	17.0/8	21,000	98,333/1
COMPUTER ASSOCIATES INTL (U.S.)	1,363/3	222.2	6,103	30.8	22.3/1	21,000	64,905/5
ORACLE (U.S.)	1,010/4	20.0	10,130	14.8	10.0/12	41,320	24,441/12

* Fiscal year; † Fiscal year 2000 figures were unavailable for this company; figures are from fiscal year 1999. Source: Standard & Poor's Institutional Market Services

COMPANY	2000* R&D SPENDING ($ MILLION)/RANK	% CHANGE FROM YEAR PREVIOUS*	2000* REVENUE ($ MILLION)	% CHANGE FROM YEAR PREVIOUS*	2000* R&D SPENDING AS % OF REVENUE/RANK	2000* NUMBER OF EMPLOYEES	2000* R&D SPENDING PER EMPLOYEE ($)/RANK
SAP (GER.)	740/5	30.0	5,080	18.1	14.6/10	21,699	34,112/11
3COM (U.S.)	611/6	−3.9	4,334	−16.7	14.1/11	10,597	57,651/6
AUTOMATIC DATA PROCESSING (U.S.)	412/7	9.9	5,540	12.5	7.4/13	37,000	11,145/14
PEOPLESOFT (U.S.)	297/8	32.9	1,429	−3.1	20.8/2	6,929	42,894/9
BMC SOFTWARE (U.S.)	294/9	58.5	1,719	31.9	17.1/7	6,677	44,032/7
AMERICA ONLINE (U.S.)	286/10	63.4	4,777	54.5	6.0/14	12,100	23,636/13
ELECTRONIC ARTS (U.S.)	267/11	8.6	1,420	16.2	18.8/5	3,100	86,225/3
NOVELL (U.S.)	228/12	1.1	1,273	17.4	17.9/6	5,629	40,440/10
CADENCE DESIGN SYSTEMS (U.S.)	219/13	22.2	1,093	−17.2	20.0/3	5,000	43,836/8
ADOBE SYSTEMS (U.S.)	201/14	−3.0	1,015	13.5	19.8/4	2,760	72,846/4
DRUGS/MEDICAL							
ASTRAZENECA (U.K.)	2,923/1	160.0	18,445	110.8	15.8/4	58,000	50,397/4
PFIZER (U.S.)	2,776/2	21.8	16,204	19.6	17.1/3	51,000	54,431/3
NOVARTIS (SWITZ.)	2,655/3	14.0	20,303	2.4	13.1/9	81,854	32,441/13
JOHNSON & JOHNSON (U.S.)	2,600/4	6.9	27,471	14.5	9.5/14	97,800	26,585/14
ROCHE HOLDING (SWITZ.)	2,365/5	11.0	17,240	11.8	13.7/8	67,695	34,940/7
MERCK & CO (U.S.)	2,119/6	−25.9	32,714	21.6	6.5/19	62,300	34,019/9
GLAXO WELLCOME (U.K.)	2,015/7	9.1	13,479	6.4	14.9/6	61,830	32,586/12
HOECHST† (GER.)	1,941/8	−4.3	22,211	−16.1	8.7/17	111,800	17,365/17
BRISTOL-MYERS SQUIBB (U.S.)	1,843/9	16.9	20,222	10.6	9.1/15	54,500	33,817/10
ELI LILLY (U.S.)	1,784/10	2.6	10,003	8.3	17.8/2	31,300	56,984/1
AMERICAN HOME PRODUCTS (U.S.)	1,740/11	5.2	13,550	0.7	12.8/11	51,656	33,684/11
SMITHKLINE BEECHAM (U.K.)	1,616/12	11.9	13,306	3.7	12.1/12	47,200	34,243/8
PHARMACIA (U.S.)	1,290/13	−21.3	9,146	26.4	14.1/7	—	—
ABBOTT LABORATORIES (U.S.)	1,194/14	−2.3	13,178	5.3	9.1/16	57,100	20,910/16
SCHERING-PLOUGH (U.S.)	1,191/15	18.3	9,176	13.6	13.0/10	26,500	44,943/5
MEDTRONIC (U.S.)	480/16	−17.3	5,015	18.5	9.6/13	21,490	22,322/15
GUIDANT (U.S.)	372/17	−5.8	2,352	23.0	15.8/5	8,360	44,498/6
BAXTER INTL (U.S.)	332/18	−32.9	6,380	11.8	5.2/20	45,000	7,378/19
BECTON DICKINSON (U.S.)	254/19	16.6	3,418	9.7	7.4/18	24,000	10,584/18
ST JUDE MEDICAL (U.S.)	240/20	140.9	1,115	9.7	21.6/1	4,379	54,873/2
ELECTRICAL/ELECTRONICS							
SIEMENS (GER.)	5,204/1	12.7	68,170	14.0	7.6/6	443,000	11,748/10
MATSUSHITA ELECTRIC† (JPN.)	4,681/2	4.0	71,527	−3.2	6.5/10	282,153	16,590/8
SONY (JPN.)	3,693/3	5.1	62,601	−1.6	5.9/13	189,700	19,468/7
MOTOROLA (U.S.)	3,505/4	21.2	30,931	5.2	11.3/3	121,000	28,967/4
PHILIPS ELECTRONICS (NETH.)	2,270/5	11.5	31,270	3.3	7.3/8	226,874	10,007/12
NOKIA (FIN.)	1,744/6	89.4	19,653	48.4	8.9/5	55,260	31,568/2
CANON (JPN.)	1,666/7	0.5	24,550	−7.2	6.8/9	81,009	20,562/6
AGILENT TECHNOLOGIES (U.S.)	997/8	5.2	8,331	4.8	12.0/2	36,400	27,390/5
SHARP† (JPN.)	494/9	−60.1	16,342	−2.5	3.0/18	—	—
INVENSYS (U.K.)	479/10	3.1	14,343	−4.0	3.3/17	121,683	3,940/16
SCHNEIDER (FR.)	441/11	10.4	8,328	9.9	5.3/15	67,510	6,530/14
ROCKWELL INTL (U.S.)	422/12	−16.4	7,043	4.3	6.0/12	41,200	10,243/11
THOMSON (FR.)	418/13	0.6	6,848	11.6	6.1/11	48,920	8,546/13

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OMRON† (JPN.)	397/14	6.2	5,199	−9.2	7.6/7	—	—
QUALCOMM (U.S.)	381/15	8.9	3,937	17.6	9.7/4	9,700	39,293/1
PIONEER† (JPN.)	291/16	0.3	5,326	1.6	5.5/14	23,647	12,325/9
THOMSON MULTIMEDIA† (FR.)	282/17	0.4	5,613	−2.7	5.0/16	46,665	6,050/15
TERADYNE (U.S.)	229/18	17.1	1,791	20.3	12.8/1	7,500	30,476/3
HIGH-TECH CONGLOMERATES							
GENERAL ELECTRIC (U.S.)	1,667/1	8.5	111,242	10.7	1.5/4	340,000	4,903/3
3M (U.S.)	1,038/2	2.2	15,659	4.2	6.6/1	70,549	14,713/1
EASTMAN KODAK (U.S.)	817/3	−11.4	14,089	5.1	5.8/3	80,650	10,130/2
FUJI PHOTO FILM† (JPN.)	793/4	4.6	13,461	4.3	5.9/2	—	—
SEMICONDUCTORS							
INTEL (U.S.)	3,503/1	31.0	29,389	11.9	11.9/9	70,200	49,900/2
TEXAS INSTRUMENTS (U.S.)	1,412/2	17.1	9,468	9.9	14.9/6	38,197	36,966/6
STMICROELECTRONICS† (FR.)	690/3	12.9	4,211	6.1	16.4/5	29,182	23,637/9
APPLIED MATERIALS (U.S.)	682/4	5.9	4,859	20.2	14.0/8	12,755	53,453/1
ADVANCED MICRO DEVICES (U.S.)	636/5	12.1	2,858	12.4	22.2/1	13,387	47,493/4
NATIONAL SEMICONDUCTOR (U.S.)	386/6	−18.1	2,140	9.4	18.0/4	10,500	36,771/7
MICRON TECHNOLOGY (U.S.)	322/7	18.5	3,764	24.4	8.6/10	15,700	20,516/10
CONEXANT SYSTEMS (U.S.)	310/8	−8.0	1,444	20.3	21.5/2	7,200	43,061/5
LSI LOGIC (U.S.)	302/9	−30.0	2,089	37.7	14.5/7	6,300	47,961/3
ANALOG DEVICES (U.S.)	262/10	19.5	1,450	17.9	18.1/3	7,400	35,430/8
MURATA MANUFACTURING† (JPN.)	243/11	8.0	3,436	1.3	7.1/11	—	—
TELECOMMUNICATIONS							
LUCENT (U.S.)	4,792/1	−5.9	38,303	20.4	12.5/6	153,000	31,320/6
ERICSSON (SWED.)	3,869/2	18.2	25,161	16.8	15.4/3	103,290	37,458/3
NORTEL NETWORKS (CAN.)	3,561/3	−7.7	21,854	18.8	16.3/2	80,627	44,168/1
ALCATEL (FR.)	2,096/4	16.6	22,885	8.3	9.2/8	115,712	18,117/8
BCE† (CAN.)	1,984/5	0.3	18,651	−17.3	10.6/7	58,000	34,202/4
NTT† (JPN.)	1,289/6	−52.3	91,089	3.0	1.4/15	—	—
FRANCE TELECOM (FR.)	590/7	−22.9	27,070	10.5	2.2/13	174,262	3,384/13
AT&T (U.S.)	550/8	−16.9	62,391	17.2	0.9/16	147,800	3,721/12
BRITISH TELECOM (U.K.)	548/9	28.7	29,713	10.4	1.8/14	132,100	4,146/11
ALSTOM† (FR.)	512/10	—	13,984	—	3.7/11	113,700	4,502/10
ALCATEL† (GER.)	406/11	—	1,898	−35.1	21.4/1	12,807	31,707/5
CORNING (U.S.)	378/12	28.7	4,741	23.7	8.0/9	21,500	17,591/9
OKI ELECTRIC† (JPN.)	319/13	−19.5	6,302	−12.0	5.1/10	—	—
TELLABS (U.S.)	304/14	49.9	2,319	36.1	13.1/5	6,997	43,400/2
ADC TELECOM (U.S.)	281/15	104.1	1,927	24.5	14.6/4	13,457	20,916/7
MATSUSHITA COMMUNICATION† (JPN.)	270/16	—	8,342	3.2	3.2/12	—	—

* Fiscal year; † Fiscal year 2000 figures were unavailable for this company; figures are from fiscal year 1999.
Source: Standard & Poor's Institutional Market Services

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[1] Based on SPECweb99 benchmark result current as of 9/20/00. See www.spec.org for details. [2] Certain enablement fees may apply. [3] Price claim based on z900 Configuration for Linux ($1,200,000) running 2500 separate instances of Linux. Storage not included. See www.ibm.com/eserver/zseries/linuxconfig for full details on this configuration. [4] IBM list price for xSeries 330 Model 865411Y with 800MHz processor, 256MB memory and open bay, not including hard drive, operating systems or other options. [5] IBM list price for xSeries 200 Model 847840X with 800MHz processor, 128MB memory and open bay, not including hard drive, operating systems or other options. [6] IBM list price for iSeries 400 Model 820, FC #2395, uni-processor, 256MB memory and 8.58GB disk. [7] IBM list price for iSeries 400 Model 270, FC #2422, uni-processor, 256MB memory and 8.58GB disk. [8] Rated #1 UNIX operating system: D.H. Brown Operating System Scorecard, 3/24/00. [9] IBM list price for pSeries 680 with 6 processors, 4GB memory and 9.1GB disk and unlimited user license for AIX 4.3.3. [10] Special price available only through ShopIBM for pSeries 640 with POWER3-II 375MHz copper chip, 1-way, 256MB memory, 9.1GB disk and unlimited user license of AIX 4.3.3. [11] Requires available Parallel Sysplex® technology. [12] In a full Parallel Sysplex cluster. [13] Price claim based on z900 Configuration for Linux ($1,200,000) running 2500 separate instances of Linux. Storage not included. See www.ibm.com/eserver/zseries/linuxconfig for full details on this configuration. Actual reseller prices on all systems may vary. List prices, specifications and availability may change without notice. IBM, iSeries, pSeries, zSeries, xSeries, Netfinity, S/390, Parallel Sysplex, AIX, WebSphere, Light Path Diagnostics, Netfinity Director and the e-business logo are trademarks or registered trademarks of International Business Machines Corporation. UNIX is a registered trademark of The Open Group. Windows and Windows NT are registered trademarks of Microsoft Corporation. Intel and Pentium are registered trademarks of Intel Corporation. Linux is a registered trademark of Linus Torvalds. All other companies or products are trademarks or registered trademarks of their respective companies. ©2000 IBM Corporation. All rights reserved.

employees, cronyism and corporate competition for resources.

But that was then. What seems different about Lucent's effort is the time spent studying past mistakes and instituting measures to avoid them, while maintaining an unusual willingness to change its approach if a better strategy appears. NVG has been used as a benchmark by some 30 firms considering similar ventures, including IBM, NEC, British Telecom and Motorola. It has also been the subject of a Harvard Business School study and a comprehensive report published by the Corporate Executive Board, a Washington, D.C.-based research organization. This last examination concluded: "After studying 16 companies attempting to do internal venturing…none have addressed all the critical success factors as thoroughly and effectively as Lucent."

Cruising the VC Champs Elysées

THIS NEW NEW VENTURES EFFORT DATES BACK TO THE EARLY 1996 trivestiture that saw the old AT&T split into its current namesake company, NCR and Lucent. In what NVG President Tom Uhlman calls a "desire to break the mold from AT&T," Lucent challenged employees to move faster and help their company grow. A lot of this nimbleness could be achieved in the business groups. But then-Bell Labs President Dan Stanzione felt his enterprise was underexploited, and that a trove of technology could not get to market speedily enough—if at all—through conventional channels.

Stanzione's challenge prompted Uhlman—then Lucent's senior vice president for strategy, development and public affairs—to propose the separate business entity that became the New Ventures Group. Fundamentally, the enterprise would be different from the programs many companies run to provide venture funding to *outside* firms that not only promise to fill technological holes but may even add to profits. Instead, NVG would concentrate on *internal* inventions. The added revenue from spinning off Bell Labs' technological booty constituted only part of the prize. Equally important was to plant seeds in fertile areas that could one day become major sources of growth. Having an alternative channel for developing technology would also set an entrepreneurial tone that it was hoped would permeate Lucent's R&D pipeline, motivating recruits and longtime employees alike.

In mid-1996, Uhlman hired former Booz·Allen & Hamilton consultant Stephen Socolof to help launch the New Ventures initiative. The pair spent months studying what had worked—and what hadn't—at similar efforts run by Xerox, Intel and others. One basic tenet they picked up was that their venture arm had to shed conservative corporate structures and act more like true venture capitalists—moving quickly and taking risks. They motored up and down Palo Alto's Sand Hill Road, the Champs Elysées of venture capitalism, culling VC success secrets. This reconnaissance drove home the imperative of due diligence—evaluating an idea's market potential, competition and so on—and then providing seed money in discrete stages, adding to the pot only if key technological or market milestones are met. Veteran VCs also advised Lucent to look outside the firm for business and even technical expertise to help consider and launch these ventures—and to provide equity compensation rather than sticking with conventional salary structures. All had proven hard to do in corporate venture arms; all were deemed essential.

Veteran venture capitalists advised Lucent to go outside the firm for expertise.

The first spinoff was launched in late 1996: a firm called Veridicom, which makes a fingerprint analyzer on a silicon chip for identification and security. About a year later, with a handful of ventures under way, Uhlman's initiative became a full business group. Despite all their precautions for quick and thorough evaluation, however, Socolof admits the initial group members were overwhelmed by scores of ideas covering everything from semiconductors to optics to the Internet. It also turned out that Lucent harbored fewer true entrepreneurs with the experience to lead spinoffs than planners had imagined.

Both factors led to NVG's bolstering its capabilities with a cadre of "entrepreneurs-in-residence." Working mainly out of cubicles in the swank, carpeted New Ventures wing—a stark contrast to the adjacent linoleum-lined Bell Labs—these tended to be young business-school types who also had experience in selected technical areas. Not only could they help evaluate ideas and develop them into workable business plans, they were also prepared to join any new venture—perhaps as chief executive or chief operating officer—to get it off the ground.

Another lesson Lucent learned was that it shouldn't try to fund its ventures alone. The original idea had been to keep total ownership of proprietary ideas. But the group soon realized that outside VCs brought added benefits that more than made up for Lucent's taking a smaller share. For one thing, they had experience in launching startups; Lucent didn't. They also carried golden Rolodexes of contacts essential to developing businesses—and in many cases enjoyed such standout reputations that just putting their name on the investor list increased the odds of success. Socolof says it initially proved tough for Lucent to grasp "this whole notion of being willing to take a smaller piece of the pie to create a bigger success." But grasp it the company did. NVG today counts some 40 VC firms as investors in its endeavors.

Doing More With Wireless

IT WAS THIS NEW, FASTER-ACTING NVG THAT RAJIV LAROIA encountered with his idea for what would become Flarion. The mathematician's studies in communications had led him to a radical concept for handling wireless data—and in October 1997, he started the Digital Communications Research Department to pursue it. Laroia's efforts went beyond e-mail and music applications, then coming into vogue, to include more sophisticated services such as videoconferencing and interactive gaming that he believed mobile people would soon want in wireless form. Planned improvements to conventional wireless systems—the so-called third-generation technology still under development—could conceivably accommodate such applications *(see "Internet Everywhere,"* TR *September/October 2000)*. But traditional systems had originated to handle voice calls, which have different technical requirements from digital data transmissions. Voice systems can tolerate typical losses of up to 1 percent of a given

conversation with no noticeable problems, largely because of the redundancy of speech. Data transmission is a lot more sensitive: The same small losses—even losses a hundred times smaller—can ruin a deal or end a game. And besides, Laroia reasoned, configuring voice-optimized systems to carry high data volumes was an expensive proposition affordable for businesses but not for the mainstream users he wanted to serve.

The way around this problem was to start from scratch with a system designed for data. (Adding voice to this would be relatively simple, since voice could be treated as just another form of data.) The key lay in improving on a well-known technology popular in wireless and digital TV and audio called "orthogonal frequency division multiplexing," which tries to get around the "multipath" interference that happens when signals bounce off trees, buildings and the like. Lucent's big innovation was to add the "flash," a term that refers to the ability to hop rapidly between frequencies. Essentially, the new system deploys multiple high-speed wireless signals virtually simultaneously over several frequencies. This spread-spectrum technique both optimizes bandwidth and minimizes interference.

Initially, Laroia's department consisted of himself and one colleague. But by mid-1998, he had hired several additional members—and things began to move. Within a year, the group was far enough along for Laroia to envision a commercial system consisting of a base station transmitter paired with a unified modem-chip set that could be integrated into cell phones, personal digital assistants and other wireless devices. He spoke with business groups about his concept, but they were squarely focused on third-generation technology and did not have the extra resources to develop such a radical alternative. Laroia felt it was far too important to let go, since if left to others it could ultimately usurp a core part of Lucent's wireless business. Still, he believed the idea had a significantly greater chance of success if it could be pursued in a more entrepreneurial environment.

Rajiv Laroia felt **his wireless idea was** too important to let go. NVG's **leaders agreed.**

That led him to New Ventures, where his proposal fell into the hands of J.C. Huang and Lars Johnnson. Huang, with a doctorate in applied physics, an MBA and consulting experience, heads up one of three core groups inside NVG. He had helped launch WatchMark, a firm specializing in network-management software. The German-born Johnnson was an entrepreneur-in-residence who had worked as a chemical engineer before joining NVG with a master's degree in technology management.

The pair liked the idea immediately and spent a couple months helping Laroia hone the concept into a workable business plan. Then it was time to meet the venture capitalists. Laroia had never been much of a pitch artist, but with Johnnson handling the business end and the mathematician touting the technology, together they wowed venture capitalists on both coasts. Backed by $12.5 million from Lucent and three leading VC outfits—Charles River Ventures, Bessemer Venture Partners and Pequot Capital—Flarion was launched this February. Johnnson signed on as director of business development, and Laroia became chief technology officer, taking his entire department with him. By summer, they had hired former NextWave and Bell Atlantic Mobile executive Ray Dolan as CEO and set up shop in a roomy 2,500-square-meter space in a modern office park in Bedminster, N.J. Even as workmen were converting an old mailroom into a systems laboratory, Flarion was up to 40 employees, and is heading toward 100 by year's end.

The initial focus is on perfecting the technology. Plans call for a prototype system to be ready late this year, with a commercial offering set for the second half of 2001. Flarion officials say they can't estimate the cost savings of their technology because it depends on network size, traffic volumes and other factors. But they stress that the savings will be significant—enough for that California family to do its Web surfing affordably. With conventional systems, quips Dolan, "I don't think anybody can afford both the automobile and the connectivity."

Even presuming it can bring wireless data into mainstream use, Flarion doesn't expect to get the bulk of the wireless pie. First come the big carriers on conventional networks—the Nortels, Ericssons and Lucents. Flarion must also contend with startups such as San Jose-based ArrayComm, which has its own dedicated data scheme. Still, Dolan foresees winning a major, and increasingly important, portion of the wireless-data business. He envisions a future for data traffic that mirrors the evolution of air freight shipping. Commercial airlines began carrying freight because they saw the chance for extra revenue. But as air freight usage grew, a separate industry sprang up to serve it; freight takeoffs and landings now rival commercial airline traffic. So it will be with data, contends Dolan. Data may have started out on conventional wireless networks. However, he asserts, "The tidal wave of demand that's about to hit carriers of wireless data will require a Flarion solution."

Back in the carpeted confines of NVG, everyone hopes Dolan is right. But it's only one of many seeds being planted, a fact attested to by dozens of paperweight-like deal icons—each commemorating successful financing rounds—covering a long birch cabinet in Tom Uhlman's expansive office. So far, Uhlman's people say they've examined nearly 250 projects in detail and launched about 25 ventures, though not all have been announced. Not every one has been a winner. Two didn't make it even to the spinoff stage. One particularly high-profile disappointment was Inferno, an attempt to develop a new operating system partially conceived by legendary Unix and C-programming-language pioneer Dennis Ritchie. The effort failed to live up to its buzz and was ultimately closed—though it has recently been reborn under a different business strategy and may yet find a way to survive.

No doubt there will be others that, as Uhlman puts it, "I wouldn't call failures, but didn't meet expectations." But the New Ventures head isn't much troubled by that right now. Indeed, he's on a roll, helping Lucent do what few companies have been able to accomplish: find ways for people like Rajiv Laroia to challenge the status quo and bolster the establishment at the same time. That task may not make for the stay-in-one-job stability of yesteryear, but for big companies and their employees, it can provide a different type of security. ◊

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Seekers: Google founders Sergey Brin (left) and Larry Page spun a university research project into the ultimate Web search tool.

Search Us, Says Google

Can't find it on the Web? The Google guys came up with a better way to sift through a billion Web pages—a stack of documents 100 kilometers high—in less than a second. As a result, they're the hottest search engine around.

Q & A

"A GREAT COMEDY DUO" IS HOW TIME MAGAZINE describes Sergey Brin and Larry Page. But these two dropouts from Stanford's doctoral program in computer science look to be the ones set to do the proverbial laughing all the way to the bank. That's because they left Stanford in 1998 to launch Google.com, and in just a couple years their search engine has become the Web's coolest.

Talk with Page and the Russian-born Brin, both 27, and one-liners are more likely to roll off their tongues than algorithms. But these are unquestionably brainy guys who started with the shared assumption that Web searching was broken: As the Web grew, finding good information got harder. So they devised a wholly new approach to sorting search results that they call PageRank: The more links there are to a page, the higher it vaults in Google's hierarchy. Another innovation: To climb high in the search results, a page needs external validation. Proprietary algorithms that parcel out rankings to pages aren't influenced by spamming and the other techniques that marketers sometimes use to boost a page's rating in other search engines. The math gets complicated—some 6,000 computers get involved—but for the user, Google is simple and easy to use.

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

When Brin and Page began talking up their sorting strategy, Andy Bechtolsheim, a founder of Sun Microsystems, heard their pitch and promptly wrote out a check for $100,000 to help seed-fund their venture. Later, the founders assembled an all-star venture capital team, with money from both Kleiner Perkins and Sequoia Capital (between them, these firms funded Apple, Amazon.com, Cisco Systems, Netscape and Yahoo!). That kiss of the gods of Silicon Valley means big things are expected of Brin, Google's president, and Page, the CEO.

And they have been delivering—a fact underscored in June when Yahoo! dumped its relationship with longtime search leader Inktomi and installed Google as its default search tool. Google is the first engine to index more than one billion pages, and it won this year's "Webby" award for technical achievement, presented by the International Academy of Digital Arts and Sciences.

Brin and Page both like talking about how they got to where they are and where they hope to take Google. They provided commentary in conversations with Northern California freelance writer Robert McGarvey.

Content is the No.1 reason visitors go back to their favourite sites

Forrester Research

- 90% of all users search for travel content (cyber dialogue)
- Of the 1 billion mobile subscribers worldwide by 2002, more than half will use Mobile Internet Services
- 73% of respondents are demanding city guide type content in a Mobile Internet offering (Nokia)

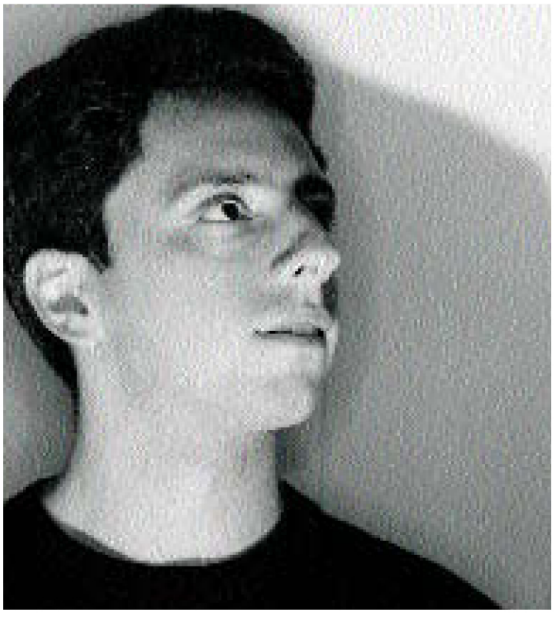
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TR: Why is the Google.com home page so simple?
BRIN: When we started, we didn't have a webmaster. The result was a nice, simple interface. And we have stayed true to that because we realized it helps people get their searches done faster. They don't want to hang out on a home page when they want to get information quickly.
PAGE: Other search companies have turned into media companies. We have remained focused on search. Over half of our company is devoted to engineering.

TR: What makes one page more valuable than another?



BRIN: The premise of our PageRank system is that a page that is pointed to by many other sites is important. In other words, external approval raises a page's ranking. That's where PageRank comes in—it is based on an analysis of the linkage structure of the Web. At the end, there are millions of variables, but we manage to do a lot of math, very fast, and in the end we rank pages in a way that's very close to how you would do it intuitively.

TR: Is Google actually any different from other search engines in how it goes about hunting for information on the Web?
BRIN: Google is different from other search engines in that the others use traditional techniques—which pages do the search terms occur on? Google factors in much more information including the link structure, fonts, headings, text of nearby pages and so forth.

TR: Why is it when I search for "Sergey" on Google, your Stanford home page comes up in the second position?
BRIN: I was kind of upset about that myself. I was upset it was not number one. I should clarify. "Sergei" is usually spelled with an "i," not a "y." And then my page has good presence on the Web. There are links to quite a few articles that I authored, and those links in turn are linked to by other pages, so my placement by the PageRank system would be comparatively high.

TR: Is there any place where PageRank doesn't work?
BRIN: There are many places where it falls down. For instance, while the technique works very nicely to measure the relative value of a particular Web page, it doesn't necessarily measure relevance: Is this page really delivering what you're looking for?

TR: Couldn't I create a series of Web pages at every site offering free space, link them to each other, and thereby create higher rankings for myself?
BRIN: No, that wouldn't work. The way the math is designed, you need external approval.

TR: Isn't there a celebrated Google failing—namely that if the search is for "What is more evil than Satan," Google points to Microsoft's home page?
BRIN: We fixed that. Now if you type in that phrase, you get articles about Google. This was a result based on technology that looks at what other Web pages are saying about a particular page. Lots of sites label Microsoft as evil—even though that is not how Microsoft is principally described. We view that as a not-great performance of that algorithm, which we've since worked on.

TR: How did you two start working together?
BRIN: I had been in the PhD program for a couple years when Larry joined in 1995. I was working on data mining, the idea of taking large amounts of data, analyzing it for patterns and trying to extract relationships that are useful. When Larry joined, he started dabbling with the Web and started gathering large amounts of data. That data intrigued me, and I wanted to run various experiments on it.

TR: Why did you start a company?
BRIN: For three years, we tried as hard as we could to avoid doing that. Of course, there was a temptation to launch a dot com. But we were pretty comfortable at Stanford. We got to a point, though, where we needed a lot of resources—for example, computers. We had snarfed a whole bunch of machines of all different types; we had sort of borrowed them from various people in the department.
PAGE: At Stanford we'd stand on the loading dock and try to snag computers as they came in. We would see who got 20 computers and ask them if they could spare one.
BRIN: But this was getting out of hand. We saw that if we started the company, we would be able to bring Google to the world quickly—we wouldn't have to spend all our time scouting for computing resources.

TR: Did you have a business plan?
BRIN: When we decided to start a company—and we actually committed to it by purchasing disks ourselves, with our own money—we spent about $15,000 on a terabyte [a million megabytes] of disks. We spread that across three credit cards. Once we did that, we wrote up a business plan and, remarkably, we have stayed close to it over the last couple years.

TR: Was it difficult to raise funding?
BRIN: The first check we got was from Andy Bechtolsheim—one of the founders of Sun, and a Stanford alum. We met him very early one morning on the porch of a Stanford faculty member's home in Palo Alto. We gave him a quick demo. He had to run off somewhere, so he said, instead of us discussing all the details, why don't I just write you a check? It was made out to Google, Inc., which did not exist at the time, and was for $100,000. So we set up a corporation, deposited the check, and by the time we closed the round we had raised almost $1 million. We continued to build our system and, after about a year, we needed more money. So we raised $25 million in venture capital. Everybody on Sand Hill Road knew who we were.

TR: I'm sure the VCs asked you time and again, What's your revenue model? How are you going to make money?
PAGE: Since we're a private company, it's

insight imagination

It's All About the Technology

impact



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not necessarily a bad thing that people are skeptical about our business model. Doubts about the viability of this kind of business probably discourage others from jumping in as competitors. But we don't have any skepticism. Our traffic is growing nicely—about 20 percent monthly. We answer 40 million queries a day, including 15 million at Google.com. That's a very significant number. Very few Web businesses have anywhere near that scale.

I won't say exactly what we make per search, but most search companies, if you dig through their financial reports, are making about a penny per search from advertising. You can do the math: 15 million queries a day is about $14 million in revenue per quarter. I am not saying we make that much currently. We've been reluctant to do a normal ad deal because we feel we do a better job by providing a highly targeted ad. By the way, if we signed a deal with a Web advertising network like DoubleClick, we would be profitable right now. But we are in this for the long term, and we want to do the right things for our business. Being profitable immediately isn't the right thing.

We have other revenue sources besides ads. We provide search to about 80 sites, including some very big ones: Netscape, Yahoo! and Cisco; that's a lucrative market.

TR: Why don't you use traditional banner ads such as would be involved in a DoubleClick deal?
BRIN: Understand that we do run ads. A lot of people say they never see ads on our site, but we show them on about 15 percent of our searches. They are text-based ads that load quickly and appear in blue boxes. They are targeted to your search. But we don't want to use simple banners. They slow down the search experience—users want to get on and off a search page quickly, and we let them.

TR: Has anyone suggested that you bring in some "adult supervision" to manage the company?
PAGE: We always try to bring in as many adults as possible. But it's difficult. There's a trade-off between technological savvy and organizational savvy. And a lot of people we would want to hire—like Jeff Bezos at Amazon.com—well, he has his hands full.
TR: How do you two work out the division of responsibility?
BRIN: Larry focuses a little more on the operations side—computers and things like that. I focus on research and marketing. But for the most part we're interchangeable. It's a great convenience to us; it gives us more flexibility.
PAGE: We're like parents—the interactions are similar. Occasionally, somebody will get upset with an answer they get and they'll run to the other parent, but we almost always give the same answer.

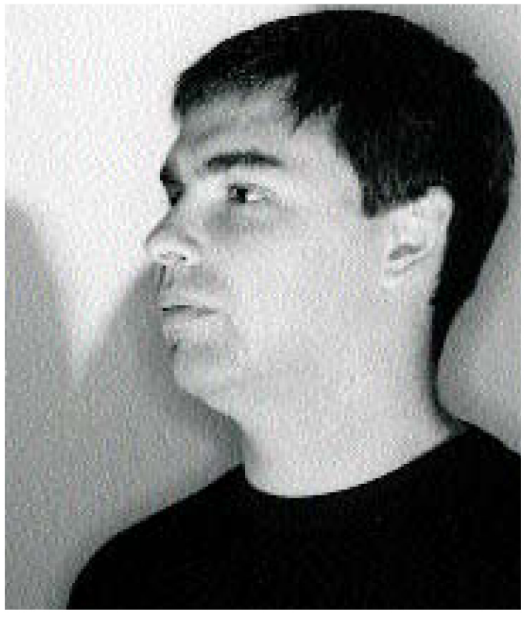
TR: A factoid making the rounds is that Google is the world's largest installation of the open-source operating system Linux. How did you come to settle on Linux as a standard?
BRIN: Linux is well supported, free and runs well on PCs. What's not to like?
PAGE: At Stanford, because we took computers whenever we could find a spare, we ended up with one of everything. And we found that the PCs running Linux were faster, more reliable and a lot cheaper than anything else.

TR: What's to stop another startup from coming along and beating Google at its own game?
BRIN: I believe the search industry is like the semiconductor industry at a younger stage—search engines are becoming more complex, and the barriers to entry are rising. Google now has over 6,000 computers. Search has become expensive.

TR: What's next for Google.com?
PAGE: We have a six-person research group that's chartered to do things that are one year away and that may or may not work. We are on a quest to build the ultimate search engine. We think it will be a smart tool that understands exactly what you want, understands all the information on the Web, and then it gives you the exact right thing. We think Google is significantly better than anything else out there right now, but we have a huge list of things to do that will take us closer to the ultimate search engine.

TR: Things like what?
PAGE: Recently we have focused on making sure we have access to all the public information in the world. We've increased the size of our index to over one billion pages, and we will be very aggressive about continuing to expand that. If you assume each Web page would involve two pages to print if you printed out our indexed pages, it would be about 100 kilometers high. And we search that in less than a second. We want to access everything available, all over the world, in all languages. We recently added Chinese and Korean. Everybody here knows that the mission is to increase people's experience when they are looking for things.

TR: Do you get acquisition offers for the company?
PAGE: Oh sure, all the time. We try to dissuade people from giving us offers,



though. We're growing at a good rate, we have been successful at attracting good people and we are increasing our traffic tremendously. We believe we are going to dominate the market—and if you believe that, it's hard for anyone to pay you enough to justify selling. Search is the number-one application on the Web. And it's easy for people to try out different search engines so they can compare. They notice differences and they tell their friends. Friends tell friends. And that's how we grow.

TR: How is running Google different from being at Stanford?
PAGE: They're kind of the same. I'm working on a lot of the same problems, just on a bigger scale. Maybe I'm too close to it to have perspective. Probably in three years, I'll sit back and say, "Holy cow, what happened?" ◊

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JDS Uniphase Corporation
JDS Uniphase
$41,000,000,000
Has Agreed to Acquire
SDL, Inc.
M&A Advisor
Pending

Vyyo, Inc.
vyyo
$126,250,000
Follow-on Offering
Lead Manager
September 13, 2000

Repeater Technologies, Inc.
Repeater Technologies
$42,750,000
Initial Public Offering
Co-manager
August 8, 2000

RF Micro-Devices, Inc.
RF MICRO-DEVICES
$250,000,000
Convertible
Subordinated Notes
Co-manager
August 7, 2000

Corvis Corporation
corvis
$990,000,000
Initial Public Offering
Co-manager
July 27, 2000

TyCom Ltd.
TyCom
$1,956,200,000
Initial Public Offering
Co-manager
July 26, 2000

JDS Uniphase Corporation
JDS Uniphase
$19,300,000,000
Has Acquired
E-TEK Dynamics, Inc.
M&A Advisor
June 30, 2000

ONI Systems, Corp.
ONI Systems
$200,000,000
Initial Public Offering
Co-manager
June 1, 2000

Stanford Microdevices, Inc.
STANFORD MICRODEVICES
$48,000,000
Initial Public Offering
Co-manager
May 24, 2000

Bookham Technology, Inc.
BOOKHAM
$306,500,000
Initial Public Offering
Co-manager
April 11, 2000

PCTEL, Inc.
PCTEL
$127,900,000
Follow-on Offering
Lead Manager
April 11, 2000

Vyyo, Inc.
vyyo
$91,100,000
Initial Public Offering
Lead Manager
April 4, 2000

Anaren Microwave, Inc.
Anaren
$121,600,000
Follow-on Offering
Lead Manager
March 27, 2000

UTStarcom, Inc.
UTStarcom
$180,000,000
Initial Public Offering
Co-manager
March 2, 2000

PCTEL, Inc.
PCTEL
Not Disclosed
Has Acquired
Voyager
Technologies Inc.
M&A Advisor
February 28, 2000

TriQuint Semiconductor
TriQuint SEMICONDUCTOR
$300,000,000
Convertible
Subordinated Notes
Co-manager
February 17, 2000

JDS Uniphase Corporation
JDS Uniphase
$5,700,000,000
Has Acquired
Optical Coating
Laboratory, Inc.
M&A Advisor
February 4, 2000

Telaxis Communications Corp.
Telaxis
$68,000,000
Initial Public Offering
Co-manager
February 1, 2000

Corning, Inc.
CORNING
$1,967,875,000
Follow-on Offering
Co-manager
January 25, 2000

Sawtek, Inc.
SAWTEK INCORPORATED
$291,500,000
Follow-on Offering
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INSIGHTFUL ADVISORS • VALUED RELATIONSHIPS • COMPREHENSIVE CAPABILITIES

Fabulous Science

STOP THE PRESSES! SHARKS DO GET CANCER. This normally wouldn't qualify as big medical news, and I barely noticed the item when it appeared not long ago in the *New York Daily News.* But think of the huge amount of mythology—and business—that has mushroomed out of a single, easy-to-grasp and, as it happens, false anecdote. If sharks are immune to cancer, wishful thinking went, they must make a protein or molecule that prevents cancer from developing. From this appealing little fiction emerged a thriving branch of alternative medicine: the use of shark cartilage to treat cancer.

It's easy to dismiss the shark-cartilage hypothesis as fairy-tale science. But appealing stories are nonetheless an integral part of the research process, as Peter Medawar shrewdly observed in his book *Pluto's Republic.* Scientific theories, he wrote, "begin, if you like, as stories, and the purpose of the critical or rectifying episode in scientific reasoning is precisely to find out whether or not these stories are stories about real life." Nowadays, telling a good story—whether it holds up or not—has become a big part of contemporary biotech and pharma.

The "story" is a kind of simple, declarative, trademark narrative that creates a feel-good association between a hypothesis, product or company and the consuming public. Those consumers need not buy medicine at the pharmacy. They may instead buy stock or, in the case of venture capitalists, "buy" the story of a startup company by providing seed money and other forms of capital investment.

The story has long been a feature of the biotech and pharmaceutical business. The writer Barry Werth formalized it as a fundamental component of biotech entrepreneurship in his book *The Billion-Dollar Molecule,* an account of "rational" drug discovery at Vertex Pharmaceuticals in Cambridge, Mass. In California, Shaman Pharmaceuticals always had one of the best stories in the business; inspired by the examples of aspirin and digitalis, Shaman's declared mission was to discover new medicines in natural compounds derived from plants from the rainforest. After several rounds with the Food and Drug Administration, Shaman transformed itself several years ago into a company primarily devoted to dietary supplements.

When it comes to stories, however, I'm not sure Medawar could have envisioned their current reincarnation as marketing tools. Almost every morning, I hear at least one ad on the radio boasting of a new medical technology or treatment available at various local hospitals. You know the ads I'm talking about: "Joe Smith was in his forties and the father of three children when he went to see his doctor about some minor abdominal pain. He was diagnosed with colon cancer. At first the cancer didn't respond to treatment. But then he heard about a new treatment at Greater Aesculapians of New York, where doctors told him the combination of several new drugs might help. His cancer is now gone. He has a lot more time on his hands, and he's spending it with his kids..."

Journalists have always been shameless purveyors of the well-told anecdote as a means of conveying a larger trend or idea. Clinical researchers, too, have been known to relay the occasional case study at conferences. But use of the heart-warming anecdote has now become a widespread tool of medical advertising, and I'm not so sure that what's been good for the goose is good for the gander.

There are still a few people left in clinical research to whom "anecdote" remains a dirty word, and "anecdotal" serves as one of the most withering of adjectives, precisely because anecdotes lack the rectifying science about which Medawar wrote. Too much data is left out, too many informational corners are cut. How long has the happy ending endured? How many people *didn't* respond to the treatment? My allergist once told me that a prescription drug heavily advertised on television works in less than 50 percent of the people who try it. Funny, but you don't get that impression from the ads.



Narratives are an essential part of science, but these days stories seem to have taken over the marketing of biomedicine—and when that happens, the public is the loser.

The most important thing about an anecdote, whether in science, journalism or marketing, is that it must be true—true not only in the particulars of the small, simple story, but true to the implications of the larger story. The first part is easy, given the intense regulatory scrutiny of drug advertising. But in the larger sense, anecdotes are often misleading, and by making mass-market promises on the basis of a narrowly true anecdote, medical innovators and drug companies may be contributing, in an invisible but pervasive way, to growing public cynicism about health care. Selling lifesaving medical treatments on radio or TV should be more complicated than selling shampoo. ◊

This column marks the final appearance of "Biology Inc." in Technology Review. *Many thanks to the readers who passed on their praise and criticism.*



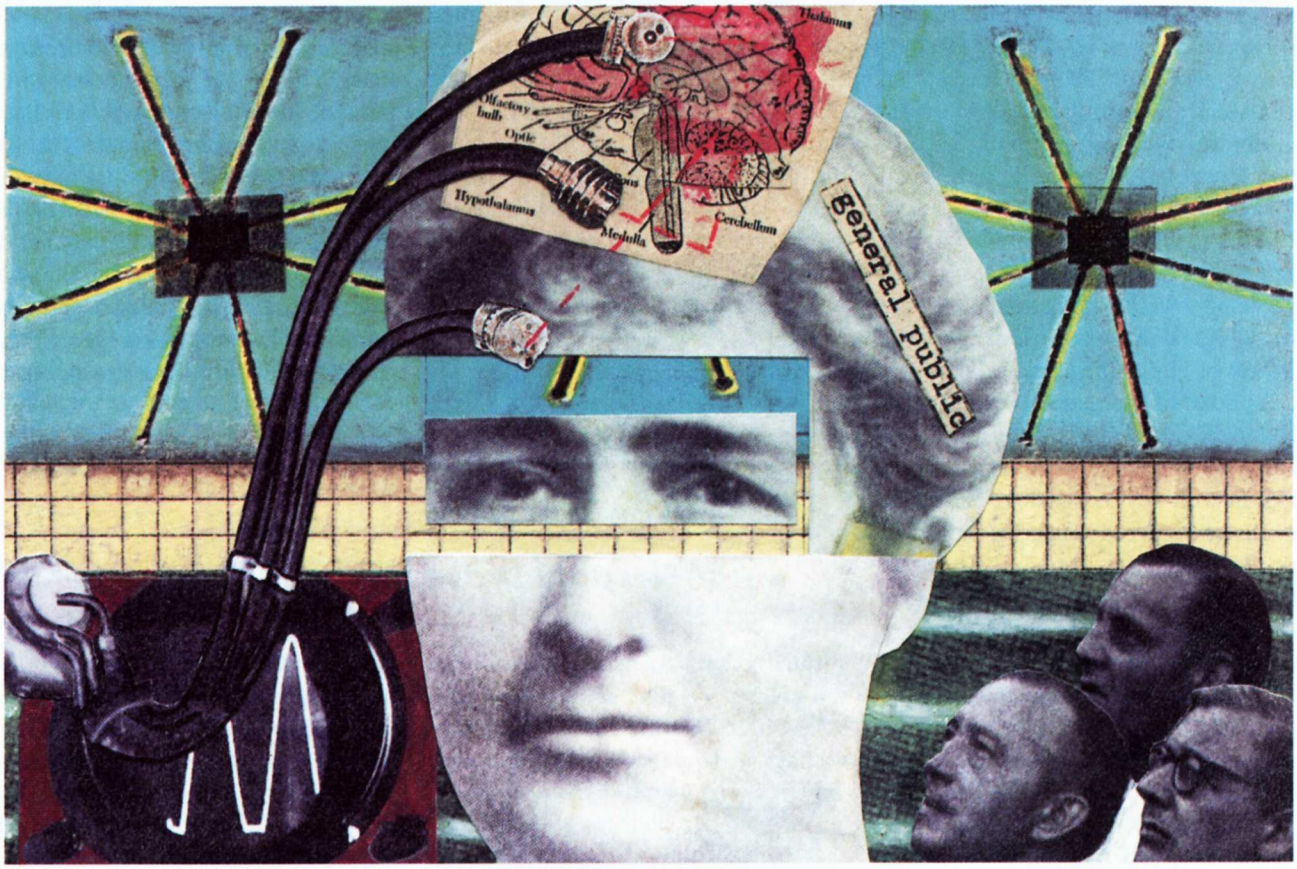
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STEVEN DANA

VIEWPOINT | BY GARY TAUBES

The Cell-Phone Scare

When fear is the opponent, science doesn't stand a chance

THERE IS A GOOD-NEWS–BAD-NEWS rhythm to the introduction of any pervasive new technology. With cellular telephones, for instance, the good news came with the explosive growth of the industry itself, which by November 1992 had recorded its 10 millionth customer. Three months later came the bad news: David Reynard, bereaved husband, appeared on "Larry King Live" with the remarkable accusation that cell-phone use had caused the brain tumor that killed his wife. Reynard, not surprisingly, was suing the cell-phone companies he held responsible. With that single anecdotal incident, Reynard set in motion a health scare that continues to play in the press and our societal subconscious to this day. If history is any indication, it will continue indefinitely. I can make this prediction free of concern about whether cell-phone use is truly carcinogenic. If it's not, in fact, our anxiety—and the amount of press that fuels this anxiety—is likely to last considerably longer. Such is the nature of fear and the nature of science, and the inability of the latter to dispel the former.

The noteworthy aspect of fear is that its shelf life is considerably longer when the object of fear is a threshold phenomenon—invisible, at the limits of detection, if not simply a figment of the imagination. This preternatural quality is crucial because both science and the human intellect have evolved to handle the material world with relative ease. After all, when automobiles kill tens of thousands of Americans each year, the mechanism of our demise is relatively obvious, as it is with guns. Anxiety is not the issue. Caution is. If science manages to unambiguously identify the agent of an illness, as happened with the AIDS virus, the shadow of impending doom is dispelled by the light of knowledge, and the medical research establishment marches off to deal with it. The rest of us, or most of us, alter our behavior accordingly and the prophylactic industry flourishes.

But we don't, by and large, panic.

If no immediate cause of death or illness can be identified, or if no mechanism links the alleged agent of our woe directly to the illness or death—as was the case, for instance, with electromagnetism from power lines, silicone seeping from breast implants or, at least so far, genetically manipulated agricultural products—then fear sets in like ice on a pond, and an entirely different set of societal forces go to work.

This is where science fails us. The primary problem is that science is incapable of proving a negative. Over the years, researchers have looked at the effects of electromagnetic radiation at cell-phone-like frequencies on cells (the biological kind) in petri dishes and on lab animals and even humans, without coming up with any particularly believable evidence that cell phones themselves would be harmful. But here's the catch: No matter how ingenious and copious the experiments, they could no more prove that cell phones do not cause cancer than they could prove the nonexistence of God. "It is scientific only to say what is more likely and what less likely," as Richard Feynman put it, "and not to be proving all the time the possible and impossible." When it comes to what is more or less likely, however, everyone has a different opinion on how to weigh the odds. That the scientific community and the lay public do so by different standards of evidence is made obvious by the common belief in phenomena—from UFOs, ESP and ghosts to the continuing incarnation of Elvis—that are not considered likely by most working scientists.

This proving-a-negative problem comes with an important corollary: Experimental science is also inherently incapable of achieving perfection. The experiment does not exist, nor will it ever, that can unambiguously throw up zeros across the board simply because the phenomenon it has set out to study is nonexistent. Rather, if done honestly, it will result in a range of values around zero, and the midpoint of this range is even likely to be above zero—a positive result, in the lingo—because it will reflect a host of subconscious factors that will push researchers to be slightly optimistic rather than rigorously detached. For those who want to believe that the phenomenon is real, the existence of these positive results, however close to zero, will constitute all the evidence they need.

This is simply a fact of human nature, one that Francis Bacon, the Abner Doubleday of experimental science, pointed out 400 years ago when he created the scientific method as a tool to overcome our inherently delusional thinking. "The human understanding is not only inclined to underrate negative evidence," Bacon wrote, "it will also exaggerate the significance of the positive evidence, being more moved and excited by affirmatives than by negatives.... Rightly and properly it ought to give equal weight to both; rather, in fact, in every truly constituted axiom, a negative instance has the greater weight." Those of us who believe in ESP, for instance, do so because we have anecdotal evidence that it does exist, despite the decades of scientific experiments that suggest it does not.

Ingenious experiments could no more prove that cell phone use does not cause cancer than they could prove the nonexistence of God.

As a result, little or nothing is needed in a scientific vein to initiate health scares, and even less to perpetuate them indefinitely. Indeed, they become inevitable and play themselves out with a certain relentless predictability. Their procession from meaningless beginnings to full-blown national anxiety could be dictated by a flowchart or programmed with simple software.

Imagine that researchers from Laboratory A decide to study the possibility that cell phones cause cancer, assuming for the sake of argument that the hypothesis is false. If the researchers do their study well and find insufficient evidence of carcinogenicity, the story ends. Until, that is, Laboratory B gets involved. These researchers are likely to be slightly less detached than their predecessors. After all, they would not have chosen this line of research had they not believed, in effect, that the work of Laboratory A left open a window of doubt. If these researchers now perform their experiments less rigorously, or interpret their data less rigorously, then they are likely to publish an article suggesting that cell phones *may* cause cancer. Or if not Lab B, than Lab C, or D, *ad* virtually *infinitum*. This report will be picked up by the press because even the hint of a suggestion that some aspect of everyday life may cause illness or death constitutes news. This is not just the way of the press, it's human nature, as Francis Bacon made clear. (A recent example is the coverage of a study on exposure to household levels of radon gas that was published in the June issue of the *American Journal of Epidemiology*. Over the years, a dozen studies have failed to show that household levels of radon increase cancer risk. When the 13th was published claiming the opposite, the newspaper headlines read: "University of Iowa Study Says Radon Greater Risk Than Thought Before." The Iowa scientists, of course, said they simply used better techniques than their predecessors. They may be right, but the odds are against them.)

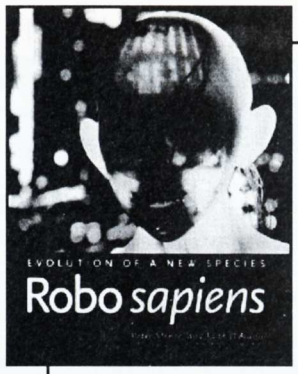
When the press publishes such reports, the relevant federal agencies have no choice but to get involved. If they do not, consumer-protection groups will accuse them of taking a cavalier approach to public health. The same goes for the relevant industry. To do nothing is to invite public reproach. Now both the agencies and the industry will respond publicly that little or no scientific evidence exists to support the claims, but they will also admit that the threat can't be ruled out. Either or both will allocate money to do proper scientific studies. If these studies unambiguously identify a mechanism by which cell phones cause brain tumors, we have a real public health threat on our hands, and the authorities are mobilized. End of fear. We stop using our cell phones, or we stop using them in a way that could be dangerous.

If these studies come up negative, however, the scientists will report that their data suggest it is unlikely cell phones cause cancer, perhaps highly unlikely. They will also admit, if they are rigor-

ously scientific, that they cannot rule out an effect. This may satisfy the public, the consumer protection groups and even the press, although the smart money would bet against it. As one consumer advocate put it in a recent news article on the cell-phone scare: "People just want to know whether phones are safe or not, yes or no." Neither—the scientifically appropriate response—eases no one's anxiety.

One other factor will come into play at this point. Experts refer to it as an epidemic of selection. We inevitably search for explanations when tragedy hits. The unfortunate individuals who have had brain tumors or have seen their loved ones succumb, as did David Reynard, will look for explanations and may seize on those that they read about in the newspapers—cell phones, for instance. The news reports on the possibility that cell phones cause cancer are likely to suggest to thousands of victims and their families that cell phones were the cause of their illness. (A number of liability lawyers will come to the same conclusion.) They will start advocacy groups and lobby Congress, and when industry-funded studies come up empty, they will suggest that the industry scientists involved had no motivation to find the truth. When cooler heads suggest that such cover-ups are unlikely, that even cell-phone company employees use cell phones and that these scientists are probably no less likely than you or I to allow innocent people to die needlessly for the sake of a modest paycheck, they will point to the cigarette industry as proof that this has happened before and so it may be happening again. As congressmen realize that votes are on the line, they will push the relevant government agencies to do more studies. But no amount of studies will resolve the residual ambiguity, will allow the scientists to say cell phones are definitively safe. The leftover uncertainty perpetuates itself indefinitely.

Eventually the anxiety-of-the-decade will fade, to be replaced in our minds and our newspapers by a more up-to-date apprehension. It would be nice to think that eventually we'll outgrow the cycle, but I have to defer here to my late mother, who was a lay expert on anxiety. The time to really worry, she used to say, is when things seem so good you have nothing to worry about. TR





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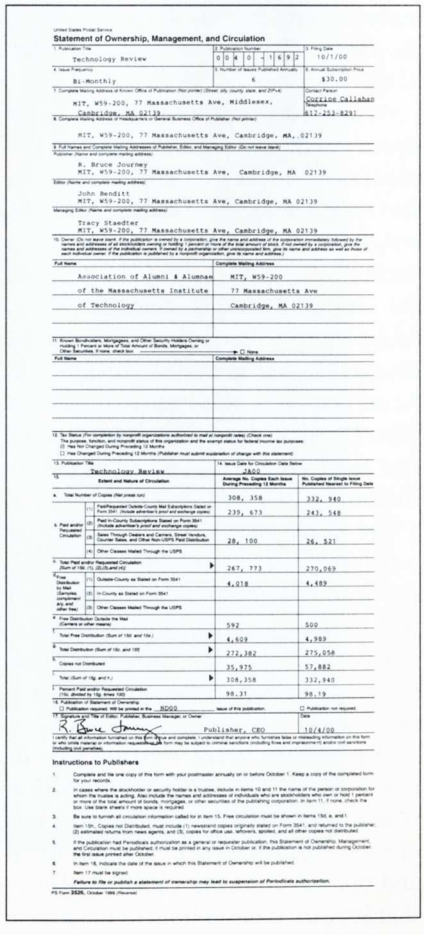
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MIXED MEDIA | BY NICK MONTFORT

Toppling the Desktop

The Mac's new OS X erodes the familiar user interface metaphor as Web browsers and the command line assert their influence.

REPORTS OF THE DEATH OF THE PERsonal computer have been greatly exaggerated. The beige box, keyboard and mouse are still serving most computer users well, while advanced interfaces such as voice recognition and virtual reality are not yet a part of ordinary computing. The trusty "windows" metaphor is going strong too. Yet one familiar PC metaphor—the desktop—may be on its way to history's virtual dumpster.

A spectacular overthrow of the desktop will soon be seen on the computer that popularized the graphical user interface in the first place: the Macintosh. Its OS X operating system, with its new Aqua interface, is now slated to appear early in 2001 (two years behind schedule). Given the pioneering role of the Macintosh in computer usability, Mac OS X could be setting the standard for interfaces in the early part of this century.

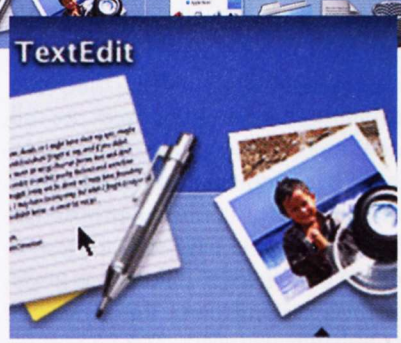
When you first boot up Aqua, it doesn't look like a radical change. Still prominent are the overlapping windows that have been around for 15 years. The sea change that Aqua brings is to the desktop metaphor, which brought us the representation of documents and folders with iconic images that can be dragged across a virtual "surface." In Aqua, you still have a trash can, which is what Einstein was said to consider the one essential piece of office furniture. But Aqua's desktop is not very desklike. There is no metaphorical surface on which to move around virtual file folders. And since many computer users now deal with computer directories far more often than they handle manila file folders, a new metaphorical system is sensible.

Aqua's transparent windows provide a new "skin" for the Macintosh. But what's most notably new in Aqua is a row of icons signifying running applications and open documents, called the Dock, that appears at the bottom of the screen.



APPLE COMPUTER

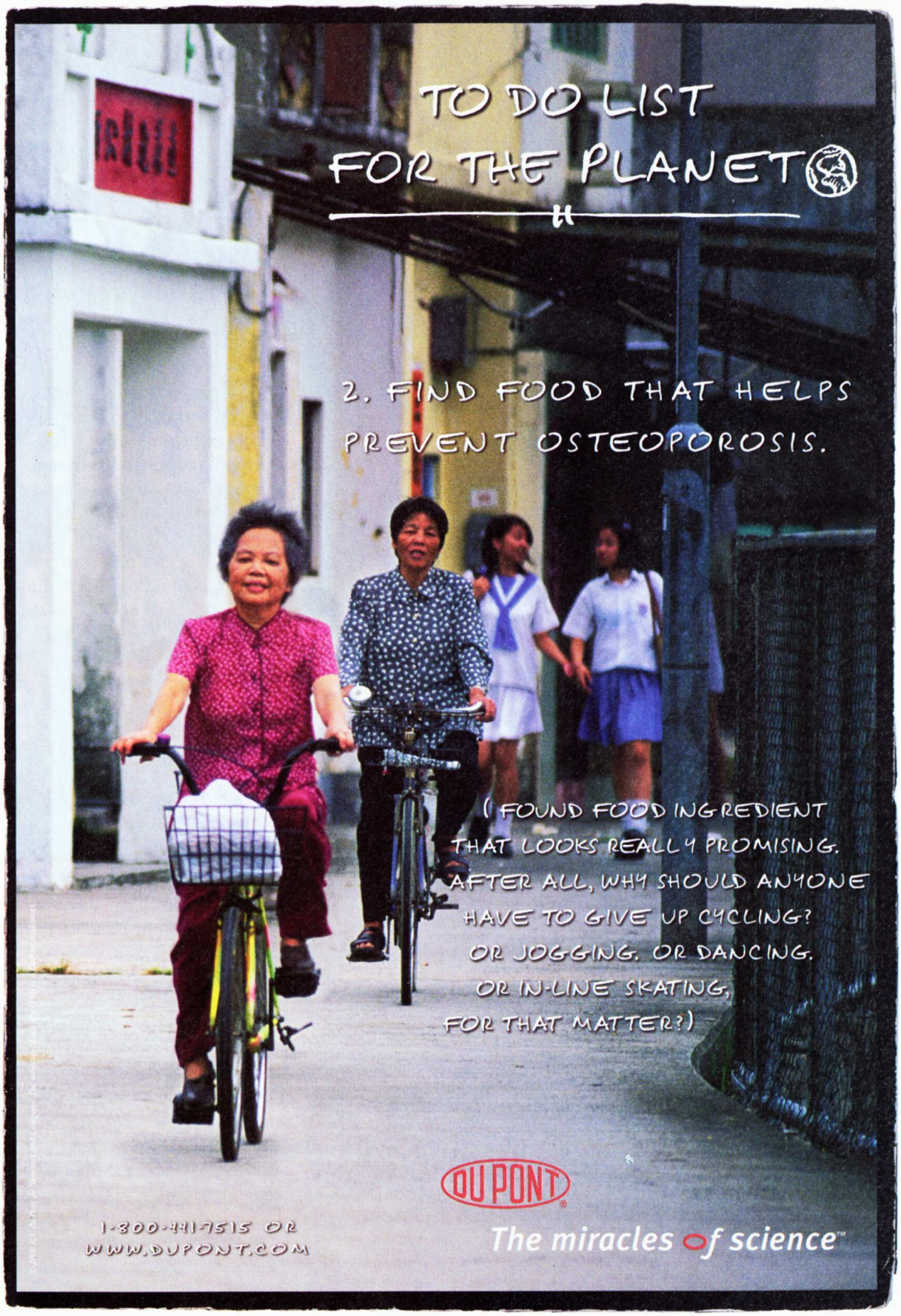
The row of icons at the bottom of the OS X screen—called the Dock—highlights Apple's departure from the desktop metaphor.



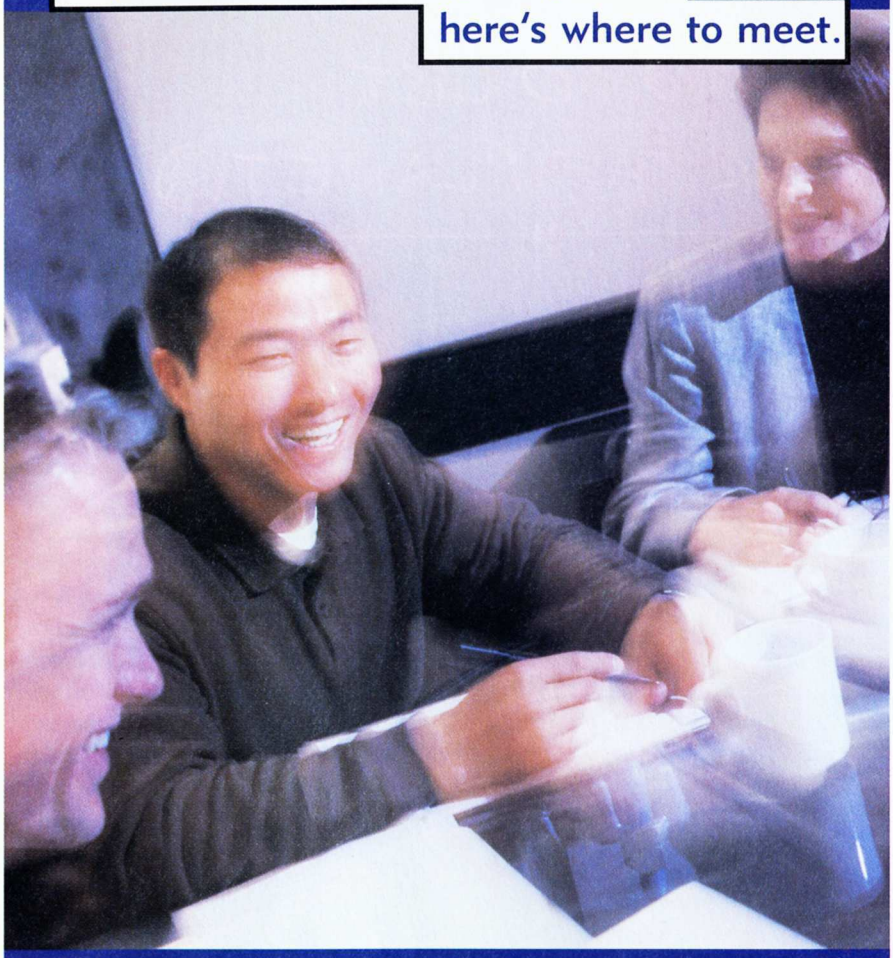
The Dock doesn't represent the desk or any other part of the office, and it doesn't even particularly resemble the waterfront protrusion its name evokes. The Dock incorporates the most useful things about menus and iconic representation without taking metaphorical baggage from the precomputing office along on the journey. The Dock borrows some from the Taskbar and Tray, elements that appear at the bottom of the Microsoft Windows interface, but its larger icons provide detailed status information, and it is a more visual element than the text-rich Taskbar.

Aqua is not without quirks. Some aspects of the interface seem crafted to wow the passing viewer rather than to enhance usability. Point at an icon in the Dock, for instance, and it grows in size, the other icons shifting to the side to make room. A nice thought, as it's then easier to see what this larger icon represents. Unfortunately, even the slightest mouse motion causes the icons to shift sea-sickeningly around. This is a slippery Dock.

While the desktop is out, the windowing aspects of the interface are little changed. Aqua is, in fact, a soft, squeezy windowing system trying to forget the blocky display of the Alto—the path-breaking graphical computer built during the 1970s at Xerox Palo Alto Research Center. Will the particular look of the Aqua be on the majority of desktop PCs in another three years? Given the influence of previous Mac hardware and software, the answer is probably yes. In any case, the way tomorrow's computer interaction works and feels will resemble OS


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X much more than it will the latest incarnation of Microsoft Windows.

A (Gasp!) Mac Command Line?

One influence on today's common computer interfaces has come not from the sort of windowing environments that lead up to Aqua, but from the Web browser—the software that, for many users, has come to define computer interaction. The Web has metaphors of its own (often mixed, as when users are required to "scroll" down a "page"). The Web page seldom imitates the desktop, though, using metaphors more closely related to the book—as when a site offers a table of contents or provides a site-specific search engine that functions something like an index. And despite the prevalence of mouse-clicking, use of the Web still depends rather heavily on good old-fashioned typing. You won't get very far online before you need to key in a URL or search terms.

It is perhaps this realization—that pointing and clicking has its limits—that led the designers of OS X to take what to many will be a surprising step. The command line, never before seen on a Macintosh in the 16-year history of the machine, is provided as an alternative interface. The "Terminal" application allows access to the Unix underbelly of the new operating system. As fans of DOS and Unix will attest, the command line is often superior to graphical manipulation—particularly when the same task is to be carried out on many files, as with "rename every file ending in '.htm' to end in '.html'." As ordinary people routinely develop their own Web sites, it makes sense that these increasingly expert users will want recourse to the command line, even if they aren't Unix gurus.

Perhaps the next big step in the everyday computer interface will be in the direction of more language-based interaction, achieving much of the power of the arcane Unix command line with most of the simplicity of simple Web queries. Windowing interfaces such as Aqua, and even a few carved-up bits of the desktop metaphor, will continue to be essential. Some of their shortcomings might be squished aside, though, by continuing to borrow from and build upon some of the better aspects of Web-based and command-line interaction. TR

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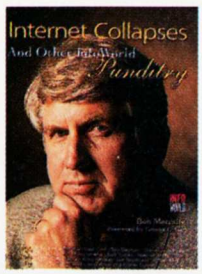
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ONE OF THE MOST liberating things a writer can do is stop caring whether readers disagree with him. That's what Bob Metcalfe did 10 years ago when he started writing a column for *InfoWorld*, the dominant trade weekly in the personal computer industry. As a result, he has felt free to make outrageous predictions, call people names, attack popular companies and organizations and deflate hype that everyone else would prefer to keep mouthing. It's all in the name of provoking thought and debate, which is what being a pundit is all about, and Metcalfe is one of the computing industry's best.

Metcalfe is the inventor of Ethernet, the founder of 3Com, the author of Metcalfe's Law (bigger networks are better) and—in the interest of full disclosure—a board member and patron of this magazine and a former employer of this reviewer. His best and most controversial columns, collected in *Internet Collapses and Other InfoWorld Punditry,* showcase Metcalfe's unique perspective as a battle-scarred entrepreneur on a decade's worth of earth-shattering events in the information-technology realm, anticipating problems and proposing reasonable remedies long before the mainstream catches wind of the issues. Metcalfe was writing in 1991, for example, that the operating-systems monolith Microsoft should divest itself of its software applications business, a conclusion that took the courts another nine years to reach.

Metcalfe is an equal-opportunity provocateur, as willing to anger Microsoft's enemies as he is Microsoft itself. For example, he dismisses the open-source software movement—"open sores," he calls it—as a "giant quilting party run by people with a tendency toward antisocial behavior." He denigrates the free Linux operating system as 30-year-old technology that will likely be trounced by Windows 2000. He criticizes the Electronic Frontier Foundation for suing the U.S. government to end export restrictions on strong-encryption technologies, calling instead for legislation to balance the needs of law enforcement and privacy. And, most of all, he criticizes Internet service providers and telephone companies for downplaying the threat of catastrophic traffic jams on the Internet and for being too slow to deliver high-bandwidth connections to homes.

Metcalfe isn't always on target, but what keeps his readers coming back for more is that when he's wrong, he's always willing to eat his words—some-

Innovation: A Look Back

This is my last book review column for *TR*. The nearly 60 volumes I've discussed over the past three years cluster around a mere handful of themes that capture how experts are thinking about technology, science, business, computing, the Internet and innovation at the turn of the millennium. As a way of wrapping up, I thought I'd describe the six most significant themes here.

Intellectual property (IP) will be one of the coming decade's bloodiest legal and economic battlegrounds. Who's got IP, who's trying to get it, and how it's being used both as a wedge and a club—those are the concerns of writers like Seth Shulman *(Owning the Future)* and Kevin Rivette and David Kline *(Rembrandts in the Attic)*. Arguing that a high-tech company is only as valuable as its patent portfolio, Rivette and Kline urge CEOs to be more systematic about their IP, locking up as many related ideas as possible. Shulman, meanwhile, decries all this acquisitiveness, especially the trend toward patenting general ideas (such as "one-click" Internet purchasing), genes and other items that arguably belong to everyone. At times, Shulman argues, the quest for legitimate profits from a patented idea may actually impede innovation and impoverish our cultural heritage. Expect to see many more books and articles about this tension.

Computers should be ubiquitous but invisible, emulating everyday objects that already work well. In *The Social Life of Information,* Xerox's John Seely Brown underscores how much wisdom is built into traditional objects and practices, and rails against "tunnel design" that values information-processing power over usability. In *The Invisible Computer,* behavioral designer Donald Norman looks forward to the extinction of the PC and previews a world of dedicated information appliances that are more powerful and reliable because they are built for a single task. MIT physicist Neil Gershenfeld develops that idea in *When Things Start to Think,* showing how much easier life could be if we embedded a bit of machine intelligence in ordinary artifacts such as paper, cash or clothing.

The Internet has changed commerce irrevocably, and businesses must adapt or die. *Sense & Respond,* edited by Stephen P. Bradley and Richard L. Nolan, and *Unleashing the Killer App* by Larry Downes and Chunka Mui show that what the Internet giveth—the ability to constantly monitor customer demand, then quickly and cheaply fulfill it—the Internet also taketh away, especially when your bricks-and-mortar business is the one that's being ravaged by an e-commerce start-up. And as *The Cluetrain Manifesto* by Rick Levine, Christopher Locke, Doc Searle and David Weinberger teaches, only the compa-

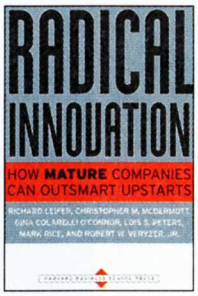
times literally. (He once famously drank a blend containing a 1995 column predicting the Internet's total collapse in 1996.) And that's a diet that would probably benefit all of us writers.

Outsmart the Upstart

RADICAL INNOVATION: HOW MATURE COMPANIES CAN OUTSMART UPSTARTS
by Richard Leifer, Christopher M. McDermott, Gina Colarelli O'Connor, Lois S. Peters, Mark Rice and Robert W. Veryzer, Jr.
Harvard Business School Press, 224 pp., $29.95

THE INTERNET STOCK BUBBLE MAY have burst, but that hasn't freed big companies from fears that their own market values could be decimated overnight by nimble startups. Never mind that most startups fail—and that they can be acquired. Corporate America still dreams of a way to domesticate innovation, for example by creating internal "entrepreneurial incubators" and "corporate venturing" departments to support ideas that wouldn't normally find a home *(see "Lucent Ventures Into the Future," p. 94).*

Radical Innovation, by a group of faculty at the Lally School of Management at Rensselaer Polytechnic Institute, encourages the notion that big firms accustomed to incremental innovation can also successfully manage the development of disruptive new technologies. To these scholars, who studied attempts at radical innovation inside 10 corporate behemoths such as IBM, DuPont, General Electric, General Motors and Texas Instruments, all that's required are solutions to seven managerial challenges: recognizing a groundbreaking idea while it's still fuzzy; coping with uncertainty over resources, expectations and leadership; defining a market for the new idea; getting the market to pay for the idea; finding resources to sustain a long-term development effort; handing off the developed product to a business unit; and keeping individual innovators motivated.



Laudable goals, all. But they read less like a recipe for success than a laundry list of things most mature companies do badly. Indeed, five years after the RPI group began their interviews, seven of the 12 projects they studied have yet to reach the commercialization stage. One project, an effort at GM to develop a hybrid gas-electric engine, flopped after internal funding ran out and external partners missed deadlines. A project at Otis Elevator to build a bidirectional elevator (similar to the turbolifts in *Star Trek*) folded after Otis overestimated the size of the potential market. And an IBM handheld electronic book project went by the wayside after two startup companies brought their own products to market.

A startup mentality and headstrong, resourceful leadership distinguished the projects that succeeded. The winning ventures all had champions whom other people described as creative, mercurial, colorful and passionate, and who were "excellent at lobbying, at bootlegging resources, and at inspiring loyalty in team members," the RPI team reports. The best way to outsmart upstarts, it seems, is to be one. TR

nies that abandon traditional marketing and recognize Internet-enabled conversations as an opportunity rather than a threat have a chance of staying relevant to their customers.

In the new economy, applications-driven research and entrepreneurship are more important than ever.
Companies with lean, product-oriented research divisions consistently lead their industries, *TR* Editor at Large Robert Buderi concludes in *Engines of Tomorrow.* But even in giant firms with full and focused R&D commitments, innovation hinges on resourceful, entrepreneurial individuals rather than teams or policies (see *Radical Innovation,* reviewed above). This is true even in supposedly group-think-dominated countries like Japan: That country's lead in areas such as metal oxide semiconductors and liquid crystal displays can be attributed to just a handful of Edison types, according to journalist Bob Johnstone's *We Were Burning.*

Scientists and engineers still have a lot to learn, notably in the areas of biology and computing.
In *What Remains to Be Discovered,* former *Nature* editor John Maddox highlights a raft of unanswered questions about the origins of life and the universe, thoroughly repudiating suggestions that the "end of science" is at hand. Despite the discovery of genes "for" traits such as novelty-seeking, for example, we're farther than ever from understanding the full relationship between genes and behavior, according to Jonathan Weiner in *Time, Love, Memory* and Richard Lewontin in *It Ain't Necessarily So.* And judging from Gerard Milburn's *The Feynman Processor* and Julian Brown's *Minds, Machines, and the Multiverse*, we still don't know whether it is possible to build a practical quantum computer—perhaps the only avenue toward big future increases in computing speed.

True innovation requires passion and a dash of madness.
Books like *Geeks* by Jon Katz and *The Monk and the Riddle* by Randy Komisar confirm that those who lack the courage to follow their own path are doomed to obscurity. The most famous, successful innovators are also a little strange: Sometimes they're hard-driving perfectionists like Edwin Land (*Insisting on the Impossible* by Victor McElheny). Sometimes they have a phobia of inactivity like Jim Clark (*The New New Thing* by Michael Lewis) or feel driven by circumstance to take outrageous risks (*The Leap* by Tom Ashbrook). And not infrequently, their creativity shades over into extreme eccentricity, as in the case of mathematician Paul Erdös (*The Man Who Loved Only Numbers* by Paul Hoffman), or even mental illness, as in the case of economist and game theorist John Nash (*A Beautiful Mind* by Sylvia Nasar).

But no book or author, thankfully, will ever discover the exact ingredients of innovation. And therein lies the grist for another century of *Technology Review.*

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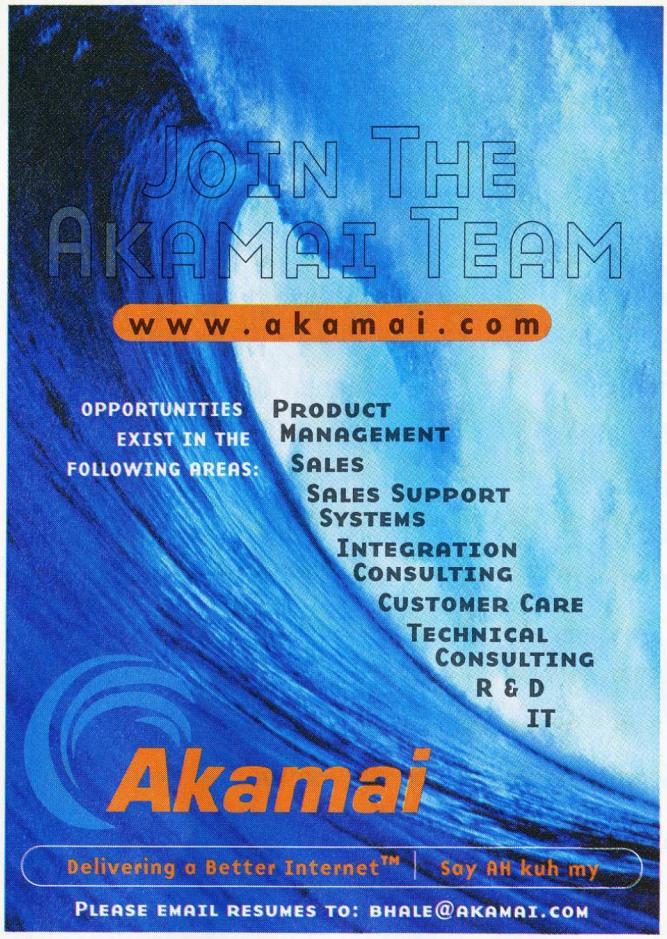
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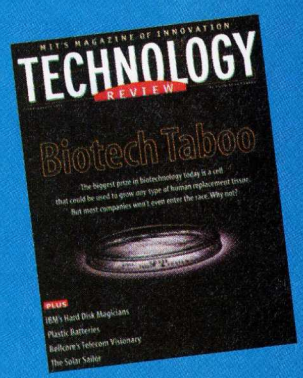
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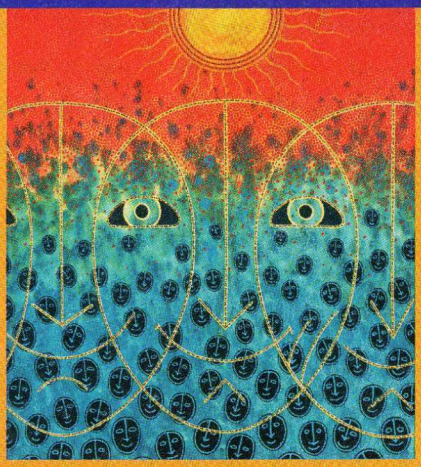
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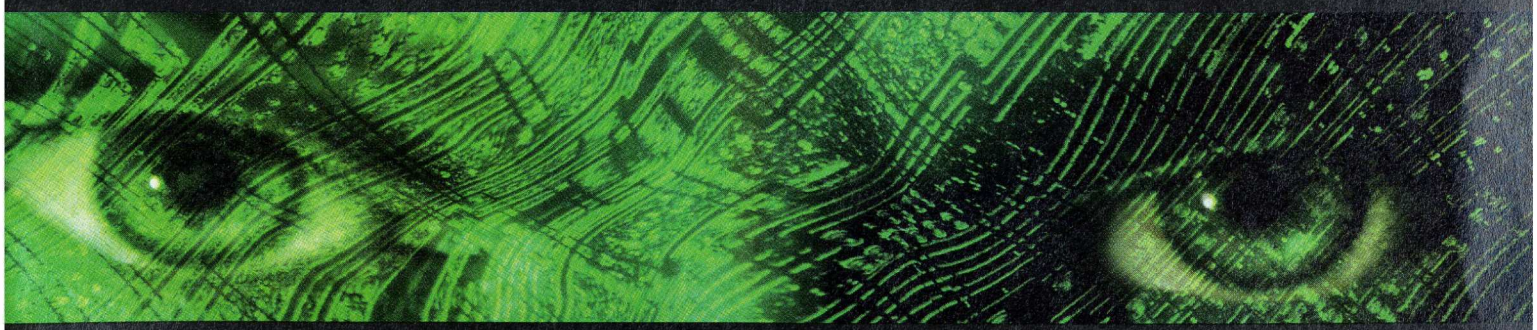
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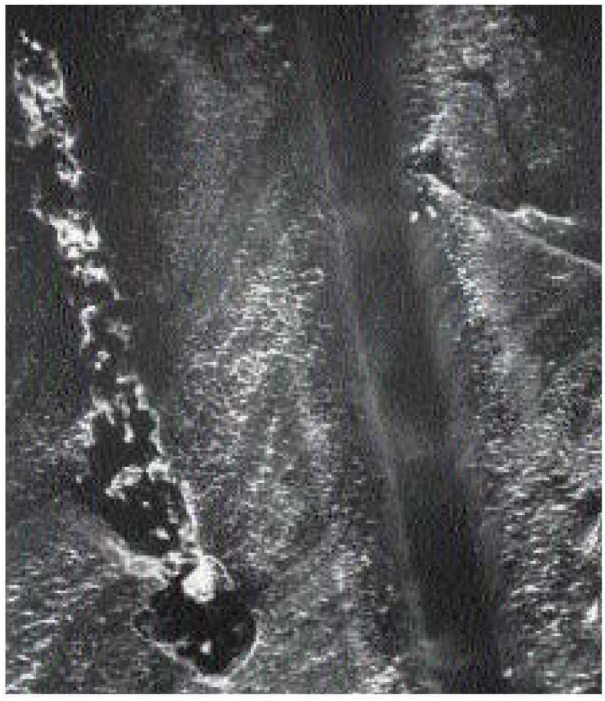
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Smooth Groove

The excimer laser is no turkey—it gave us scarless eye surgery

THIS YEAR, AN ESTIMATED 1.5 MILLION NEARSIGHTED Americans will trust their eyes to laser-wielding surgeons. While the so-called LASIK (laser-assisted in-situ keratomileusis) procedure carries risks, many will toss their glasses and give thanks to their doctors. What they don't know is that a leftover Thanksgiving turkey deserves credit too.

Just a few years after the 1960 invention of the laser, doctors began to use the new tool in eye surgeries, burning off tumors, for example, or "welding" torn retinas back together. But the technology of the 1960s and 1970s wouldn't have allowed surgeons to operate on the cornea—the clear front portion of the eye whose curvature helps determine whether a person is nearsighted, farsighted or has eagle eyes—because the colors of laser light available at the time passed right through clear materials without doing anything to them. What's more, because the first-generation lasers worked by heating tissue, they left scars.

But in 1977, the German company Lambda Physik marketed the "excimer laser," which beamed out ultraviolet (UV) light, capable of cutting transparent materials. Within a couple of years, a chemist named Rangaswamy Srinivasan at IBM's Research Division noticed another interesting fact about the new laser: Instead of burning a plastic material he aimed it at, the UV light etched a clean groove. Srinivasan brought his finding to his manager, James J. Wynne, and in October 1981, Wynne, Srinivasan and colleague Samuel Blum had a brainstorm: If the excimer laser was used in surgery, it might make incisions that would heal without scars.

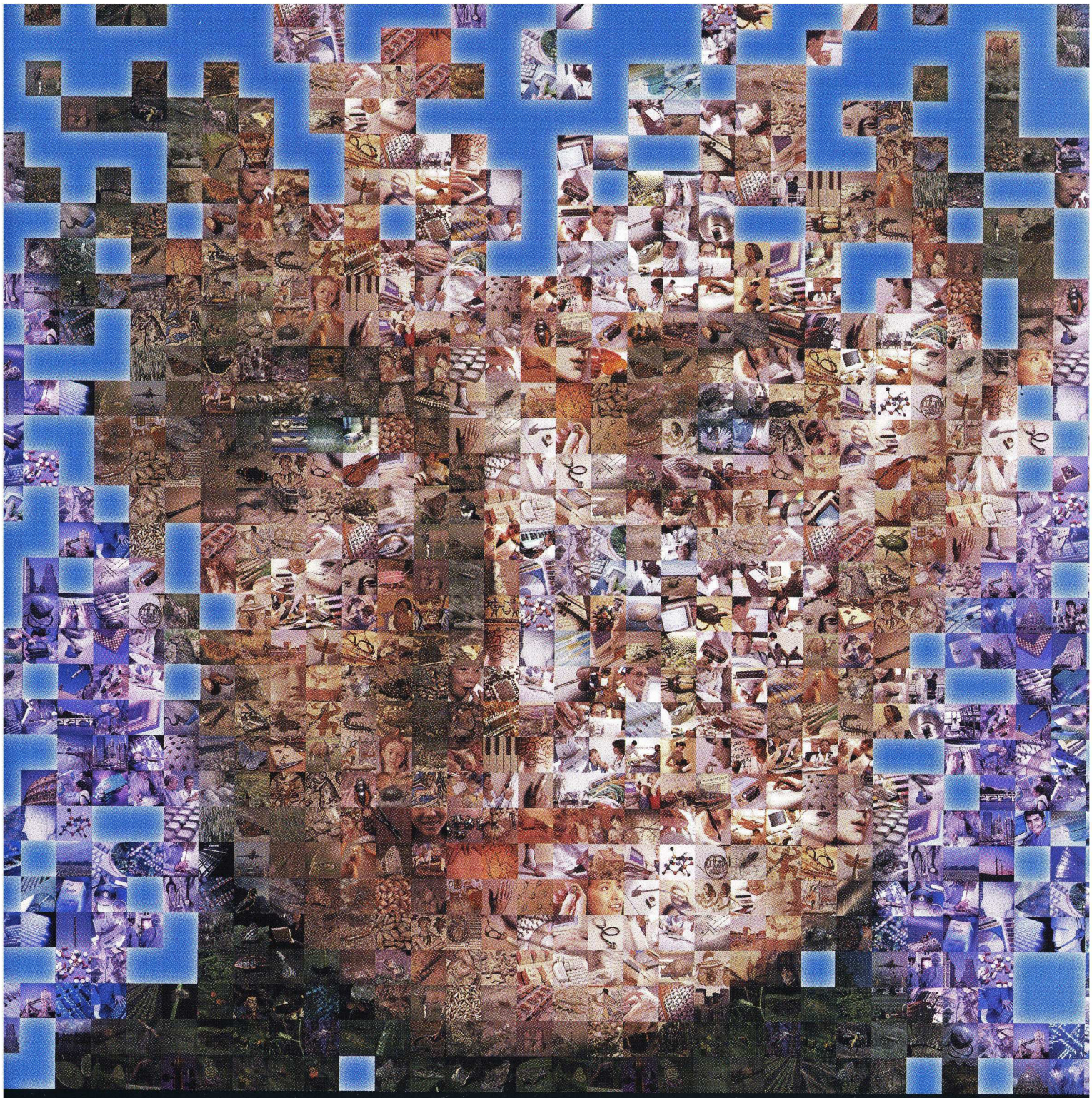
Srinivasan and Blum performed the key experiment just after Thanksgiving, pointing the UV beam at some cartilage from Srinivasan's leftover turkey. Sure enough, the laser etched a smooth groove without damaging nearby tissue. That first cut is shown in two views above, to the right of a charred cut that Wynne made with a traditional laser. By New Year's Eve, Wynne had drafted a patent application covering surgical and dental uses of the excimer laser.

Exactly what happened next has been the subject of a labyrinthine series of legal and patent battles. Suffice it to say that doctors and researchers quickly saw the potential of the excimer laser to correct vision deficits, and set about perfecting new surgical techniques. LASIK—to date the technique that works best and requires the shortest healing time—won FDA approval in 1999, becoming the most popular elective surgery in the United States. ◊

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